TIGHT BINDING BOOK

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PUBLISHERS' NOTE

The present volume is the outcome of a suggestion made to the Publishers by Mr. Allan Ferguson, D.Sc., of the East London College. Asked by a young friend how the doctrine of evolution now stood after the general upheaval of fundamental theories in the last twenty years, Dr. Ferguson was unable to refer him to any recent authoritative statement on the subject by British scientists.

The Publishers decided to make an attempt to have this want supplied. The question whether such a project was capable of execution depended upon whether the co-operation of representative British scientists could be secured. The list of the contributors, as printed on page v, gives answer to this question.

The duties of the editor have been to collate the various sections, and to prevent overlapping where it might have occurred.

CONTENTS

CHAPTER IV

Biology

By Conwy Lloyd Morgan, D.Sc., F.R.S.

CHAPTER V

Botany

By Frederick O. Bower, Sc.D., D.Sc., F.R.S.

CHAPTER VI

Zoology

By Ernest W. MacBride, M.A., D.Sc., F.R.S.

CHAPTER VII

Physiology

By Marcus S. Pembrey, M.A., M.D., F.R.S.

CHAPTER VIII

Anthropology

By G. Elliot Smith, M.A., M.D., F.R.S.

CHAPTER IX

Mental Evolution

By WILLIAM M'DOUGALL, M.B., F.R.S.

CHAPTER X

Physics and Chemistry

By FREDERICK SODDY, M.A., F.R.S.

CHAPTER XI

Time and Space

By ALFRED A. ROBB, Sc.D., D.Sc., Ph.D., F.R.S.

CHAPTER XII

Philosophy

By A. E. TAYLOR, M.A., D.Litt.

CHAPTER XIII

The Religious Effect of the Idea of Evolution

By The Rev. James Maurice Wilson, D.D., F.G.S.

LIST OF PLATES

EVOLUTION

CHAPTER I

Cosmogony

Primitive Cosmogonies

As the present book bears witness, the concept of evolution has permeated almost every branch of natural science. Its writers trace evolutionary processes in man and beast, in trees and flowers, even in the inanimate chemical elements. Our remote ancestors had no conception of such detailed evolution, but often had vague ideas of evolutionary development having occurred in the universe as a whole. While they thought that men and birds had been men and birds from their creation, they speculated that the earth, sun, moon, and stars had perchance in some remote past been quite other than they are now. Thus it was through the door of cosmogony that Evolution entered the temple of Science.

Naturally enough the most primitive cosmogonies of all display no conception of evolution or gradual change. Generally they predicate only a simple creative act; a supernatural being, who may stand anywhere in the scale of life, from a crow or a raven to a magnified old man, takes raw material and fashions the earth and the heavens much as a potter takes clay and fashions his vessels. The process may be even more rudimentary: the creator-hero of the Thlinkit Indians merely steals sun, moon, and stars out of a box and hangs them up where they illuminate the earth. In the cosmogonies of more intellectual races, the conception of æons or ages of development begins to appear. For instance the Mexicans recognized five æons which they described as " suns "—the suns of earth,

of fire, of air, of water, and of the present. Often there was no clear idea of evolutionary change occurring during the progress of an æon; each æon would end with a terrific physical catastrophe or cataclysm of the general nature of the Deluge which occurs in so many cosmogonies, and it was through these catastrophes that development occurred. Only when we reach the age of Greek Culture do we find unmistakable traces of the true evolutionary idea.

No early cosmogony contemplated the creation either of heavens or earth except out of some already existent raw material; the creation of something out of nothing was far too abstruse a concept for the primitive thinker. Thus every cosmogony encounters two problems, the first being concerned with the nature of the primeval world-stuff, and the second with the process of forming it into worlds. But it was not until Greek intellect came into play that the first problem was seen to exist at all.

Greek Cosmogony

Six hundred years before Christ we find Thales of Miletus (640–546 B.C.) speculating that water was the original raw material of the universe; the earth, which he regarded as a flat disc, was supposed still to be floating in an ocean of the elemental fluid. To him all things, although made of water (*πάντα ὕδωρ ἐστί*), were full of gods, and he conceived that the attractive powers of magnets showed them to be specially endowed with souls. During the succeeding century the claims of water to be the basic substance of the universe were challenged first by Anaximander, who saw the elemental principle as " something intermediate between fire and air on the one hand and water and earth on the other ", and then in turn by Anaximenes and Heraclitus who urged the claims of air and fire respectively. Finally Empedocles (*c.* 490–430 B.C.) put forth the doctrine of the co-existence of the four elements, fire, air, water, and earth, each eternal, indestructible, and unchangeable, from whose union in different proportions all things were made. In its general philosophic outlook this doctrine, at least in the

form in which Plato gives it in his " Laws ", is not far removed from modern evolutionary cosmogony. Plato's Athenian introduces the thesis that " all things come, have come and will come, into existence either by nature, by art, or by chance ", and amplifies his doctrine as follows:

" The philosophers say that fire and water and earth and air all exist by nature and chance and none of them by art, and that the bodies which come next in order—the earth, sun, moon, and stars—have been created by means of these absolutely inanimate existences. The various elements are moved by chance and also by inherent forces according to certain affinities amongst them—of hot with cold, dry with moist, soft with hard, and according to all the other accidental mixtures of opposites which have of necessity happened. After this fashion has been created the whole of heaven and all that is therein, as well as all animals and plants and all the seasons. These come from these elements, not by any action of mind or of any God, or from art, but by nature and chance only."

Largely as a consequence of the approval of this doctrine by Plato and Aristotle, the learned world was content with cosmogonies of this vague type for the next two thousand years—until, in fact, Bacon had impressed on men the importance of testing all scientific conjectures by a direct appeal to nature, and Newton had made them familiar with the existence of natural laws of universal applicability. The time had now come to make a bonfire of all speculations which were unsupported either by comparison with observation or by reasoning based on natural knowledge, and to clear the road for a scientific cosmogony.

The Cosmogony of Kant

The earliest cosmogonies to appear were those of Descartes (1644), Swedenborg (1734), and Kant (1755). The first of these could hardly be called scientific, and the authors of the last two were in no sense scientists. The cosmogony of Kant is, nevertheless, of interest, in that it anticipated in many respects the more famous " nebular hypothesis " of Laplace.

Kant appears to have been stirred to scientific speculation by reading a summary of an English book, *A New Theory of the Universe*, by Thomas Wright of Durham. The " new theory " was a theory only of the present arrangement, not of the evolutionary development, of the universe, and its only cosmogonic interest is that of having aroused Kant.

Kant took as his raw material a limitless waste of primordial matter, which he supposed to consist of hard atoms or molecules of the type described by Lucretius. As a result of their mutual gravitational attractions, these atoms fell in upon one another, and as they continually collided with, and rebounded from, one another, became ever hotter and hotter, just as the bullet becomes hot on striking the target. In brief Kant's raw material was initially an enormously vast cold nebula; in the first stage of its evolution it was a less vast hot nebula. This was, and still is, in accordance with scientific knowledge, but at the next step Kant was called on to pay the price of his ignorance of fundamental mechanical principles.

A well-known scientific principle, called the " Conservation of Mass ", asserts that mass can neither be created nor destroyed. It may appear to be destroyed when, for instance, we drop a bank-note into the fire, but if we collect all the ashes and other products of combustion, we shall find that these are together equal in mass, although not in value, to the original bank-note. An equally well-known principle, called the " Conservation of Energy ", asserts that energy can neither be created nor destroyed. The energy of the bullet may seem to disappear when it strikes the target, but both the bullet and the target are heated, and if we could measure the precise amounts of heat generated, the energy represented by their total would be seen to be equal exactly to the original energy of the flying bullet. A third principle called the " Conservation of Angular Momentum " asserts that rotation can neither be created nor destroyed; the total rotation, measured in terms of angular momentum, remains constant. It should be explained that in measuring the angular momentum of a system of rotating bodies we have to take account of the direction of the rotation—if the

rotation of one body is reckoned as algebraically positive, the rotation of a body rotating in the opposite direction must be reckoned as algebraically negative. The total rotation of two rapidly rotating bodies, as measured by their total angular momentum, may be zero if the bodies are rotating in opposite directions. This principle, like the two others just mentioned, may often appear at first sight to be violated, but never is in actual fact. A boy increases the rotation of his top by lashing it with a whip—where does the rotation come from? The answer is that the action of the boy's arm as he plies his whip would set him rotating backwards if it were not for the friction of his feet on the ground; this friction, acting on the earth, causes it to rotate more or less rapidly, according to direction, than it otherwise would have done, and the algebraic sum of the angular momenta of the earth and top remains absolutely unaltered. If the boy now leaves the top to itself, the friction between the peg of the top and the ground diminishes the speed of rotation of the top, but this again, according to direction, increases or decreases the speed of rotation of the earth, until finally, when the top lies lifeless on the ground, the earth resumes its original speed of rotation. All that the boy has been able to do is to transfer temporarily a certain amount of angular momentum from the earth to the top. He could no more have created rotation in the top out of nothing than he could have created the top itself out of nothing.

Kant violated this principle of the " conservation of angular momentum " by supposing that the collisions of his atoms generated rotation. The more the atoms of his nebula collided, the faster, according to him, the nebula spun, until finally it spun so fast that rings of matter were thrown off from its equator. The nebula now looked rather like Saturn surrounded by its rings, a system which Kant adduced as an example of the process he described. Each ring was next supposed to condense into a planet, the remaining central mass forming the sun. In due course each planet, going through similar experiences, surrounded itself with satellites, the final result being a complete solar system of the type we know

The Nebular Hypothesis of Laplace

The next serious cosmogony to appear, which proved to be the most famous and enduring of all, was published by the great French mathematician Laplace in 1796. Although apparently written in complete ignorance of Kant's cosmogony, the two resembled one another in many respects. Laplace, who naturally did not make Kant's mistake of supposing that rotation could be generated out of nothing, arrived at Kant's hot rotating nebula by the simple expedient of taking it for the raw material out of which his worlds were to be formed. He supposed this primeval hot rotating nebula to cool and in so doing to contract. Now the angular momentum of a big rotating nebula is greater than that of the same nebula shrunken to a smaller size but still rotating at the same rate, consequently the principle of "conservation of angular momentum", which requires that the angular momentum shall not diminish, shows that the speed of rotation of the nebula must increase as it contracts. Accordingly Laplace, quite legitimately, supposed his shrinking nebula to rotate ever faster and faster.

As a result of our earth's rotation, everything on its surface is acted on by a centrifugal force which tends to drive it away from the axis of rotation. Owing to the slowness of the rotation this force is comparatively feeble, and bodies stay in contact with the earth's surface because gravity, which tends to retain them there, is far more powerful than centrifugal force. If the earth were to increase its speed of rotation the preponderance of gravity would lessen; if it rotated once every 85 minutes instead of once every 24 hours as at present, the two forces would be exactly balanced at the earth's equator. When this balance was exactly struck, objects at the equator would have no weight; they would neither press on the ground nor fly off into space, but would, like Mahomet's coffin, remain suspended in the air wherever they were placed.

Laplace imagines his nebula to continue to shrink and so to rotate ever faster, until this stage is reached. The ring of particles which form the equator then exert no pressure on

the rest of the nebula, and as this shrinks from under them they are left suspended in space. Ring after ring of particles is left behind in this way, and, just as in Kant's cosmogony, the matter of these rings in time aggregates into planets, the central mass ultimately forming the sun. A repetition of the process surrounds the planets with satellites.

Although this hypothesis held the stage as the central figure in cosmogonic theory for well over a century, it has by no means escaped criticism, and the present general opinion of astronomers is that these criticisms compel its abandonment. The criticism which perhaps has done most to undermine the theory, that put forward by Babinet in 1861, is based on the insufficiency of the angular momentum of the present solar system. To have broken up in the way imagined by Laplace, the sun must have had a certain calculable minimum amount of angular momentum. Where has it gone to? It no longer resides in the solar system; the total present angular momentum of the whole solar system, sun, planets, satellites, and all, if concentrated in the sun would cause it to rotate about once in ten hours and to show about the same amount of flattening as is shown by Jupiter. But Jupiter is still very far from breaking up through excess of rotation, and so would the sun have been in the past if endowed with only the present total angular momentum of his system. It is, of course, not absolutely impossible, although it is certainly very improbable, that at some time a strange star, wandering into the solar system from outside, may in some way have carried off the missing angular momentum in disentangling himself. For this and other reasons, Babinet's criticism cannot be regarded as absolutely unanswerable. A far more deadly criticism is suggested by recent research; mathematical theory predicts that a stellar body breaking up from excess of rotation ought almost certainly to break into two approximately equal masses, and observation reveals countless examples in the sky of precisely the type predicted. In fact the end of the Laplacean process, at any rate on a stellar scale, is a binary star—two stars of nearly equal mass revolving about one another—and nothing in the

least resembling a solar system. We have another instance of abstract thought creating a theory, and abstract research and observation combining to destroy it.

Modern Cosmogony

This last reflection suggests that cosmogony may most profitably attempt to advance by keeping abstract thought and observation, so far as possible, hand in hand. At present, perhaps, theory has rather outrun observation, so that a telescope will prove more profitable than a library, and the sky will tell us more than the writings of theoretical cosmogonists. The cosmogonist who attempts to learn directly from the sky cannot expect to live long enough to watch the fulfilment of evolutionary changes, but he finds samples of stars in all stages of their careers and a bit of wit enables him to construct the evolutionary chain from these. So a traveller entering a forest of trees in a strange land cannot stay to watch the growth of the individual trees from seedlings to maturity, but if he can find trees in all stages of growth, the knowledge he will obtain by arranging these in order is only one degree less certain than that he could obtain by staying to observe the life-histories of individual trees. From the labours of generations of travellers in the forest of the sky it has recently emerged that, broadly speaking, all the stars are trees of one species. Terrestrial trees may be deciduous or evergreen, male or female, and so on, but stars are just stars. There is only one evolutionary chain to be pieced together, so that, for instance, every star in the sky gives us a picture of what our sun either has been at some time in the past or will be at some time in the future.

So sweeping a generalization as this naturally requires some limitation, and must in any case be explained with care. To superficial observation the most noticeable difference, indeed almost the only difference, in the stars is a difference in apparent brightness. This difference of course results in large part from differences of distances. Modern astronomical methods, however, make it possible to determine the distances of great numbers of stars and, after allowing for the effect of

variations of distance, the stars are still found to show enormous differences in intrinsic brightness, or, to use the scientific term, in luminosity. Canopus, which appears as the second brightest star in the sky, is too far off for his distance to be measured with any accuracy. But we know that he is so far off that he must be at least 10,000 times, and more probably 50,000 times, as luminous as our sun. The eclipsing star V Puppis, whose distance can be measured with fair certainty, shines with just about 10,000 times the luminosity of our sun. If either Canopus or V Puppis were put in place of our sun we should be scorched to cinders within a few moments; the seas would boil away and the solid rocks be raised to a red heat. An example of the other extreme of luminosity is provided by our nearest known neighbour in the sky, Proxima Centauri, a star so faint that, in spite of his extreme nearness, he has only quite recently been discovered. His luminosity is about a ten-thousandth part of that of the sun. If he were put in place of our sun we should receive less than 100 times the illumination we receive from the full moon; in the intense cold which would result, the seas, the earth, and probably the atmosphere itself would rapidly freeze solid. There is no reason to think that Proxima Centauri represents in any sense an absolute end to the scale of luminosity; he was discovered only because of his nearness to us, and there are probably great numbers of still fainter stars which, being both fainter and remoter than Proxima Centauri, have not yet been discovered at all. There are good reasons for thinking that at least half of the stars in the universe are quite dark, and there is probably a continuous gradation of luminosity from these up to the stars of highest luminosity, such as Canopus and V Puppis, with 10,000 or more times the luminosity of our sun.

With the aid of the spectroscope, the astronomer analyses the light of a star into its constituent parts, and from this analysis he can deduce *inter alia* the temperature of the star's surface. From analogy with glowing coals one might perhaps have expected that the most luminous stars would be the hottest, but this does not prove to be the case. Often enough they are

rather cool, and it is the enormous size of their radiating surface, rather than any specially high temperature, that is responsible for their high luminosity. By a triumph of instrumental skill, for which the credit must be given mainly to Professor Michelson of Chicago, it has recently been found possible to obtain direct measurement of the diameters of certain bright stars—to give some idea of the difficulty of such measurements it may be mentioned that none of these stars subtends an angle as great as is subtended by a pin-head at a distance of six miles. The star α Orionis (Betelguese) was found to have a diameter of 215,000,000 miles, and so must have a radiating surface about 80,000 times that of our sun, but, because his surface is so much cooler, he only emits 5000 times as much light and heat.

Stars which are somewhat less luminous than this are found, in general, to have hotter surfaces, and the rise of temperature continues until we come to stars whose luminosity is only 100 or 50 times that of our sun. Here we encounter surface temperatures of 10,000° C. or more, ranging up to perhaps 30,000° C. These are the highest surface temperatures met with; on passing to stars of still lower luminosity, luminosity and temperature are found to decrease together. Stars whose luminosity is only about equal to that of our sun have surface temperatures of about 6000° C., a temperature somewhat higher than that of the electric arc. Finally the stars at the end of the scale as known to us, the faintest visible stars, have surface temperatures of only from 2000° C. to 3000° C., not much hotter than a hot coal fire. And there is very little doubt that the series descends, could we but see it, to still colder stars whose luminosity is not far from zero.

The masses of the stars vary much less than their luminosities; the most massive star known has not much more than 70 times the mass of the sun, while the least massive has about a seventh of the sun's mass. Thus although the star α Orionis already mentioned has about 20 million times the volume of the sun, it is tolerably certain that it has not got 20 million times the mass; its enormous area of surface merely indicates that the matter inside is of very low density. Of the quantities

we have been discussing, masses and temperatures show a far smaller range than do luminosities and densities. To a first, although very rough, approximation, it is permissible to think of all the stars as having the same masses and the same temperatures, so that variations of luminosity merely represent variations of density, high luminosity indicating a vast expanse of surface and therefore low density, and conversely.

In actual fact, this law of low density accompanying high luminosity and vice versa, which we have obtained by such rough and ready methods, is fully confirmed by a precise study of the densities of the stars. The most luminous stars are found to have densities ranging down to less than a thousandth of that of ordinary air, and so must of course be in the gaseous state; the least luminous are fully as dense as the solid earth and there is a continuous transition between the two. The sequence of luminosity, temperature, and density may perhaps be suggested by the following table, in which certain prominent stars are taken as landmarks:

Type of Star.	Luminosity in Terms of Sun.	Colour.	Temperature (Centigrade).	Density in Terms of Water.	
Most luminous of all	10,000 or more	—	—	—	Giants
α Orionis ..	5000	Red	3,000°	$\frac{1}{1,000,000}$	Giants
α Persei ..	300	White	7,000°	$\frac{1}{10,000}$	Giants
γ Cassiopeiæ	50	Blue	17,000°	$\frac{1}{15}$	
Sun	1	White	6,000°	1·4	
Proxima Centauri ..	$\frac{1}{10,000}$	Red	3,000°	—	Dwarfs
Least luminous of all	Probably no limit	—	—	5 or more	Dwarfs

Giant and Dwarf Stars

The division of the stars into the two classes of giants and dwarfs, indicated on the extreme right-hand of the table, needs a word of explanation. In 1906, Professor Hertzsprung, of

Leiden, found that the red stars fell into two clearly defined classes, the one containing stars of very high luminosity, and the other stars of very low luminosity. There were no stars at all of intermediate luminosity. Since the surfaces of all red stars are approximately at the same temperature it was clear that the stars in the first class were of very great size, and those in the second class were of very small size. These two classes of star he called "giants" and "dwarfs". Eight years later Professor Russell, of Princeton, showed that this division into two classes was by no means confined to red stars. It was exhibited by every colour and type of star, although it was less marked in the hotter stars, and finally disappeared altogether in the hottest stars of all, the blue stars. The stars could accordingly be arranged diagrammatically in the form of a Λ, one leg being occupied by "giants" and the other by "dwarfs".

This discovery led Russell to a new view of stellar evolution. Up to then the prevailing belief had been that stars came into existence in the condition of the hottest stars of all, i.e. as blue stars. This belief was based, first, on a vague conviction that stars must be born out of nebulæ, and, second, on the observed circumstance that many of the blue stars are either involved in nebulæ or surrounded by wisps of nebulous matter. The supposition, however, that the stars started life at the apex of the Λ, where the hottest stars were represented, implied that a star such as α Orionis, represented at the foot of the "giant" leg of the Λ, was at the end of its career, although emitting 5000 times the radiation of the sun, an obvious absurdity. Russell accordingly advanced the view that evolution proceeded up the giant leg of the Λ, and down the dwarf leg. A star such as α Orionis was now, much more convincingly, regarded as at the beginning of its career, blue stars such as γ Cassiopeiæ, which had to be placed at the summit of the Λ, had already reached middle age, dwarf stars such as our sun were on the declining path, and the red dwarfs such as Proxima Centauri had reached extreme old age. The stars could be thought of as a vast army marching over the mountain peak presented by the

A, and, as they marched, their evolution progressed continuously from low density to high and from high luminosity to low.

Nothing was said as to the rate at which this march progressed. That the stars were scattered along the line of march might be due to either of two causes; they might have started at different times or they might be progressing at different rates. As the more massive stars were found to cluster on the "giant" branch and the less massive on the "dwarf" branch, it was possible to suppose either that the less massive stars ran their evolutionary courses more rapidly than the giants, or else that they had been created first. Clearly a further discussion of this question calls for knowledge of the speeds at which the evolution of different stars progresses.

The Source of Stellar Energy

The reason why a star runs an evolutionary course at all instead of staying perpetually in its present condition, is that it is continually radiating energy. To maintain the radiation of an electric light bulb energy must be supplied continuously from a dynamo; if the supply is cut off the filament runs a course, with extreme rapidity, through the colours white, yellow, red, plum, to darkness. Now the star V Puppis, with 10,000 times the luminosity of the sun, is radiating energy at a rate which, if the energy were brought in from a power station, would require the consumption of 500 million million million tons of coal a second. No external source of energy is known which could supply more than a very minute fraction of this energy, so that we must suppose the star to be radiating away energy from an internal supply. For a long time the nature of this supply has been one of the central puzzles of astronomical physics. A simple calculation shows that all sources which produce radiation under terrestrial conditions, such as combustion, chemical action, radioactivity, the falling in of matter under gravity, are totally inadequate. The total energy obtainable from all these together could hardly have kept a star such as V Puppis radiating at his present rate for more than 5000 years, and it is incredible that V Puppis and

all similar stars should be such recent creations; astronomical history is not as short as this. Suggestions have been made that an adequate source of stellar radiation may be found in the energy set free when the protons and electrons of which matter is formed rearrange themselves to form new elements—in other words, the evolution of the chemical elements in a star's interior was supposed to provide the radiation of the star. But there is no reason for thinking that the proportion in which the elements occur in a newly born star is substantially different from that in which they occur in older stars, and even if they were, the progress of atomic physics has made it appear probable that the only process of rearrangement which would liberate any great amount of energy would be the combination of hydrogen atoms to form heavier elements, a possible source of stellar energy which was at one time suggested by Professor Eddington.

Previous to this, the present writer had suggested that the total annihilation of matter would provide a possible and adequate source of stellar energy. The combustion of one pound of coal produces approximately enough energy to work a one-horse-power engine for an hour or to generate one commercial " unit " of electricity. The pound of coal in burning combines with a certain number x of pounds of oxygen, and the union of the two produces $x + 1$ pounds of ashes, gases, vapours, and so forth. But every atom which was present in the coal is still present in these products of combustion; although there has been a redistribution there has been no destruction of matter. Suppose, however, that in some way the positive electric charges in these atoms could be caused to combine with the negative electric charges so that they completely destroyed one another; there would now be an actual annihilation of matter. The theory of relativity enables us to calculate with the utmost precision the amount of energy which would be set free by the annihilation of any specified amount of matter. The principle of the calculation is very simple. Matter possesses mass, and radiation possesses mass. When matter is changed into radiation the principle of the conservation of mass, already explained, enables us to say exactly how much radiation corre-

sponds to a given amount of matter. It is found in this way that, whereas the burning of one pound of coal would produce about one unit of electricity, the annihilation of one pound of coal, or, indeed, of any other substance, would produce 11,340 million units of electricity.

If the energy of radiation of V Puppis came from the combustion of coal, this, as we have already seen, would have to be burnt at the rate of 500 million million millions of tons a second. But if it comes from the absolute annihilation of matter of any kind, this need only be annihilated at the rate of 40,000 million tons a second. The total mass of V Puppis being about 40,000 million million million million tons, it is clear that he can radiate at his present rate for a very long time before his supply of energy is appreciably reduced; in actual fact, radiation at the present rate for 300 million years would reduce his mass by only 1 per cent. On account of our sun's lower luminosity, it will require 150,000 million years of radiation at the present rate to reduce his mass by 1 per cent.

The Course of Stellar Evolution

If this is the true source of a star's energy, every star's mass ought continually to decrease as he runs his course and his luminosity decreases. There are strong reasons for thinking that this actually happens. Again like the traveller in the forest we cannot stop to watch the change in any individual stars, but in the samples of stars at present available for our inspection in the sky, luminosity and mass are found to vary together in a perfectly definite way, so much so that it is possible to predict a star's mass within fairly narrow limits from a knowledge of his luminosity and vice versa. This fact by itself might merely mean that the least massive stars had lived the longest or had run their course most quickly. Both of these hypotheses lead to difficulties, and by far the simplest course is to suppose that as a star gets older its mass and luminosity diminish together. This view is by no means yet universally accepted by astronomers, but as it is the only view which does not lead to confusion and difficulties, it seems to be worth pausing to examine

its consequences. Its acceptance compels us to regard the evolution of a star as resulting primarily from a wastage of his mass. A star's mass becomes his primary characteristic, and when we know this we know its position on the evolutionary chain. Differences of luminosity, density, surface-temperature, &c., in the stars are consequences mainly of differences of mass, so that luminosity, density, and surface-temperature may be regarded as secondary characteristics. It will be understood that these secondary characteristics are only approximately, not absolutely and precisely, determined by the star's mass. In the same way, in a forest of pines of all ages, to return to our previous simile, we might take the height of the pine as its primary characteristic and might regard the girth of its trunk, the spread of its branches, &c., as secondary characteristics. While the height of the tree would not absolutely fix these secondary quantities, it would enable us to guess at them with fair precision. We could rule out as grotesque the possibilities of a pine six feet in height having a hundred-foot spread of branch, or of one a hundred feet in height having only a six-foot spread of branch. The following table, giving details of six stars all of which have very approximately the same mass as our sun, will show what range of secondary characteristics is possible in stars of similar mass.

Star.	Mass in Terms of Sun.	Luminosity in Terms of Sun.	Density in Terms of Water.	Surface Temperature (Absolute Centigrade).
Procyon	1·13	6·14	0·24	6800°
ζ Herculis *b* * ..	1·09	5·20	1·05	5700°
Sun	1·00	1·00	1·38	5860°
α Centauri *b* * ..	1·14	1·39	0·37	5000°
70 Ophiuchi *b* * ..	1·05	0·705	0·43	4400°
α Centauri *f* * ..	0·97	0·724	0·14	3700°

* The letters *b*, *f* have reference to the brighter and fainter constituents of binary stars.

What is remarkable is not that stars of approximately equal mass differ in their secondary characteristics, but rather that they differ so little. The range in any secondary characteristic is very small compared with the range shown by the stars in general, as is at once evident on comparing this table, which refers only to stars of one mass, with the table on p. 11, which refers to stars of all masses. The stars, although not following one another in Indian file, march along a clearly defined track, and even if this track is fairly broad, the territory it covers is still small in comparison with that in which no stars are to be found. While not forgetting the breadth of the track, we can most conveniently picture the progress of stellar evolution by fixing our attention on a typical star which travels along the middle of the road. We can imagine the star's progress recorded by milestones placed along the road, and perhaps, as with human life, the most convenient milestones are those that record the passage of the years. When our typical star has the mass of Sirius he is losing 1 per cent of his mass in 24,000 million years; when his mass is that of the sun he loses 1 per cent in 150,000 million years, and so on. At every stage of the road we can calculate the rate of progress towards the next stage, so that it is an easy matter to reckon the time of transit between any two points of the road. From the most massive of all stars to Sirius the time interval is about 1,200,000 millions of years; that from Sirius to the sun is 6,400,000 millions of years, while from the sun to the least massive of known stars, Krueger 60 f., the time interval is about 192 million millions of years. The stars move rapidly over the first part of their road because here they are squandering their substance rapidly; it is the last part, during which their loss of mass is slight, that takes the time. The total stretch of road from the most massive to the least massive of known stars is one of about 200 million million years, by far the greater part being occupied by stars less massive and less luminous than our sun. This may explain why stars less luminous than our sun are so very common in the sky, while stars more luminous than Sirius are exceedingly rare.

The Ages of the Stars

This, however, opens up further questions. The road ends in darkness and annihilation, but where does it begin? And how far back can we trace the history of any special star, our sun, for instance, and what is the story of its birth? We conjecture that, after a certain interval of about 6,400,000 millions of years, Sirius will be reduced in mass to about the mass of our sun, and that his secondary characteristics will then be similar to those of our present sun; but can we say that 6,400,000 million years ago our sun was similar to Sirius in mass and in secondary characteristics, or are we to suppose that he has been born in the meantime?

Many reasons, all of them unfortunately of a technical nature, conspire to show that we must accept the former alternative for the great majority of stars similar to our sun, if not for all. One of the most convincing of these reasons is supplied by a study of the velocities with which the stars move through space. No star, of course, describes a straight line indefinitely; it is always under the gravitational attraction of every other star in the universe, its motion being at one moment retarded, at the next accelerated, and at another pulled away from its rectilinear path. To compare great things with small, the stars are similar to the molecules of a gas, where each molecule is for ever interfering with the progress of every other molecule it meets. After this interaction has gone on for long enough in a gas, a state is reached in which the energy is divided indifferently between all the different kinds of molecules present. This does not mean that all the molecules have precisely the same amount of energy; in actual fact they will all have different amounts. It means that if we took the hundred molecules which had the greatest energy, or the hundred having the least energy, each hundred would form a fair sample of the whole; this results from the more massive molecules having on the average the lower velocities and the less massive ones the higher velocities. A tendency to a similar condition is found among the stars, and it can be proved that this condition is

exactly that which would be brought about if the stars had influenced one another for ever. The length of time required to bring about an imperfect approximation such as is observed is found to be of the order of millions of millions of years. Although we cannot say that any individual star has lived for this length of time, we can be fairly confident that the great majority of stars have done so.

Confirmatory evidence is provided by the binary stars. A binary star consists of two stars each describing an orbit about the other, such a system as would, for instance, be formed if the earth were suddenly made as massive as the sun. A large proportion of binaries appear to owe their origin to the fission of a single mass; we have already seen that as any mass shrinks its rate of rotation continually increases, so that ultimately a stage may be reached at which it can no longer hold together as a single mass, and, after a series of cataclysmic surgings, it reappears in the form of two stars rotating about one another. A new-born binary is observed to have an almost circular orbit, whose dimensions are so small that the two constituents are almost in contact. As a result of the gravitational pull of passing stars, this orbit gradually loses its circularity and also increases in size. Thus each binary star carries its own record of the extent to which it has been influenced by its neighbours, and we can estimate the age of a binary system from its orbit just as we can estimate a horse's age from its teeth. For stars in the stage of development of our sun we find that the time necessary to produce the observed orbits is of the order of millions of millions of years.

Still further evidence is provided by a study of the ratio of the masses of the two constituents of binary stars. At birth the two constituents are of unequal mass, but since the larger mass radiates away more of its substance than the smaller mass, not only absolutely but relatively, the masses necessarily tend towards equality with advancing age. This is in actual fact observed to be the case, and the difference in mass ratio between newly-born and old binaries gives an indication of the age of the latter. It is possible to calculate these ages with very con-

siderable precision, and the results agree very closely with those calculated from the observed rates of radiation of the stars in general. For instance, the average observed mass ratio of stars of what is technically known as spectral type F—i.e. stars slightly more white in colour than our sun—indicates an age of about 4,500,000 millions of years, which is just about the time they would require to develop from the giant state by loss of radiation.

Let us pause to review for a moment the conclusions to which we have so far been led. We have seen that all the stars fit on to a single evolutionary chain, and that the position of a star on this chain is determined by its mass. As a star gets older its mass decreases, the disappearing mass leaving the star in the form of radiation. The end of a star, and indeed, so far as we can see, of the whole material universe, is simple—it is annihilation—

> Like the baseless fabric of this vision,
> The cloud-capped towers, the gorgeous palaces,
> The solemn temples, the great globe itself,
> Yea, all which it inherit, shall dissolve,

and either leave no rack behind, or, in so far as anything is left behind, it will be intangible radiation travelling endlessly through space. The question inevitably suggests itself, whether this is perhaps only one side of the picture. We see radiation being generated out of matter every day of our lives, indeed every time we look towards the sun. Is there a converse process by which matter is generated out of radiation, so that the universe passes through endless cycles of births and deaths? If so, to what final end? If not towards annihilation, to what Nirvana is everything moving? Here we can speculate and inquire as we please, but the goddess shows no sign of giving an answer; contrary to her wont, she does not even hint how we can find out for ourselves. The limit of our knowledge is that at present matter exists, or at least has enough of the attribute of existence to make us think it exists; as to what, if anything, it was before it was matter we know nothing.

The Birth of Stars

Nevertheless we can be confident that the matter of a particular star, previous to forming that star, formed something else. Stars are not born out of nothing but out of already existent matter, and the astronomer knows where to turn his telescope to watch their birth. Tracing the stream of stellar life back to its source, we pass in review more and more massive stars shining with ever higher and higher luminosity, and existing in more and more tenuous states. To find the actual source we search for matter in the most luminous and most tenuous state of all—we look to the nebulæ. Many varieties of nebula are known, but one, to which the general designation of " spiral nebula " or " white nebula " is given, far outweighs all others in importance, in size, and in the number of known examples. Nebulæ of other varieties appear to be accidents, freaks, by-products, or remnants, but these are the standard article. It is true that they appear in many shapes and forms, but all are believed to fall on to a single evolutionary chain. In their earliest stages these nebulæ appear as circles or ellipses, as in fig. 1, or sometimes, as in fig. 2, as ellipses whose two ends are drawn out to a point. The mathematician interprets this series of figures without difficulty; they are precisely the figures assumed by masses of gas rotating at different speeds. A single mass of gas, shrinking and so continually increasing its speed of rotation, would assume all these shapes in succession, and there is every reason for thinking that each nebula passes through the whole series in turn, beginning with the approximately circular form and ending with the shape shown in fig. 2. It is possible to predict on theoretical grounds what shapes will be assumed by the gas when it shrinks still further; indeed the course of events is almost identical with that postulated by Laplace in his nebular hypothesis, which we have already discussed. The nebula in fig. 2 is rotating about an axis which lies parallel to the longer edge of the page at such a rate that gravity and centrifugal force just balance along its equator. As Laplace showed, the next stage must be that the particles

which now lie along the equator will be left suspended in space by the shrinkage of the main mass from under them. In time a state is reached in which the present equatorial plane of the nebula is largely occupied by these deserted particles while the main mass rotates at the centre. Laplace suggested Saturn's rings as a probable instance of this formation, but a better example is provided by the nebula shown in fig. 3, and again by the nebula in fig. 4, in which the same process has extended still further. This interpretation of these nebular configurations requires that they should be in rapid rotation about an axis at right angles to their equatorial plane, so that it is of interest that the spectroscope has actually revealed rotation of this kind in a large number of them. Indeed the nebula shown in fig. 3 has the special distinction of being the first nebula in which rotation was observed.

It may be thought that these nebulæ, if viewed from along their axes of rotation, would prove to be of circular cross-section, like Saturn's rings. Some nebulæ are known which, at least approximately, exhibit circular cross-sections; such a one is shown in fig. 5. These circular cross-sections are, however, the exception rather than the rule. On theoretical grounds a nebula isolated in space ought undoubtedly to be of circular section. On the other hand, no nebula is isolated in space. Every actual nebula has neighbours, which will raise tides on its surface just as the sun and moon raise tides on the surface of the earth. On the nebular equator there will be two points of high tide and two points of low tide just as on the earth, so that the equator will not be strictly circular but slightly elliptical. For this reason the matter left behind as the nebula shrinks will not form a system of circles as imagined by Laplace. At any instant matter will be shed only at two points of the nebular equator, namely the two points of " high tide ", and the whole of the matter shed will form two long filaments, starting out from two antipodal points of the equator.

This consideration explains the normal appearance of the spiral nebulæ when viewed from along the axis of rotation; the matter outside the central body generally forms two long

Fig. 4.—Nebula in Coma Berenices (N. G. C. 4565)

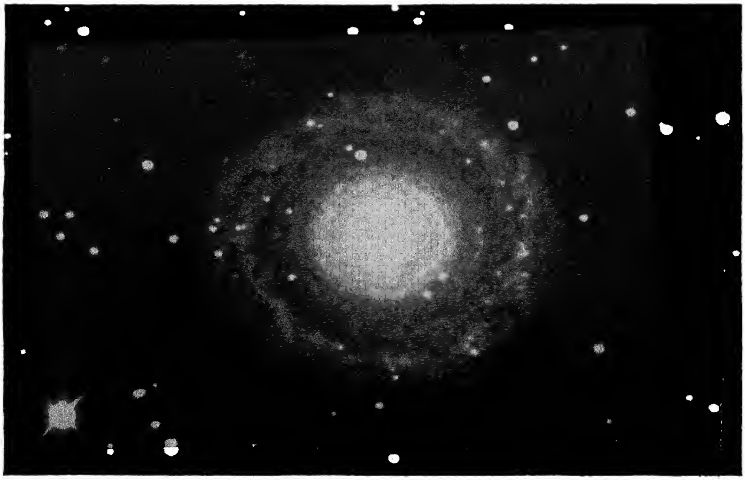

Fig. 5.—Circular Nebula (N. G. C. 7217)

Fig. 1.—Circular Nebula (N. G. C. 4649; M. 60)

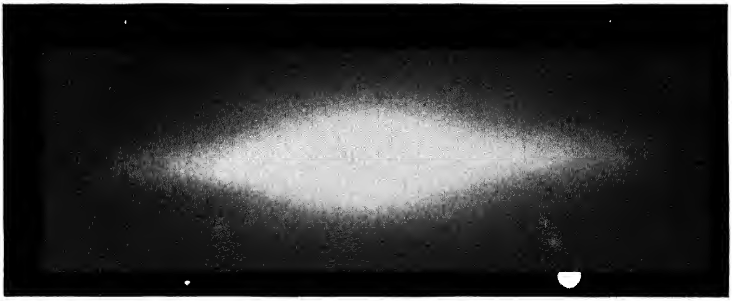

Fig. 2.—Lenticular Nebula (N. G. C. 3115)

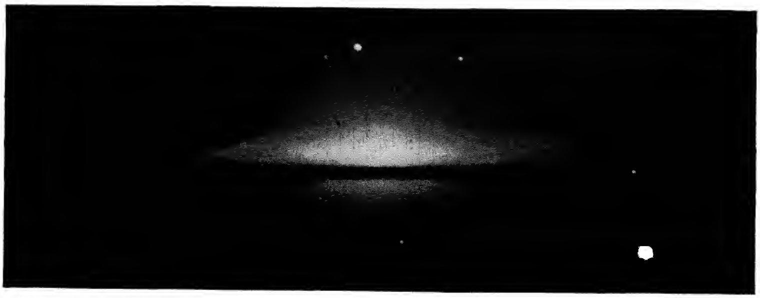

Fig. 3.—Nebula in Virgo (N. G. C. 4594)

filaments which appear to be streaming out from two opposite points on the equator of the nebula, precisely as required by theory. Such a nebula is shown in fig. 6, and another, of somewhat different type, in fig. 7.

The nebula shown in fig. 4 exhibits a lumpy or granulated appearance in its arms. In figs. 5 and 6, the granulations are more pronounced and indeed take the form of almost detached condensations. In fig. 7, the process has gone still further and, in the outermost part of the nebula, the condensations have developed into distinct and star-like points of light.

Mathematical theory predicts that if the arms of gas are sufficiently massive to cohere together in the way observed, then condensations must of necessity form in these arms. An exceedingly tenuous arm of gas would not hold together at all, it would scatter throughout space just like the gas from an ordinary gas-tap. When the stream becomes massive enough to condense into distinct arms, the process of condensation inevitably proceeds one stage further and the stream breaks up into globules of gas, much as a jet of water breaks into drops.

Theory not only predicts that these globules must form, but also provides a relation connecting the mass of each with the distance from its neighbour. Another relation between the same two quantities is provided by measures of the apparent brightnesses of the condensations and of their apparent distances apart in the sky. From these two relations we can determine both the masses of the condensations and their distances apart. By comparing the latter quantity with the apparent distance in the sky, we can estimate the actual distance of the nebula from us.

The calculation of the masses is the one which most immediately concerns us. The condensations are found to be comparable in mass with the stars; certainly more massive than the average star, and probably just about as massive as the most massive of known stars. There is little doubt that they are in actual fact newly-born stars, and that in our photographs 1–7 we have been watching the birth-process of the stars. Thus the end of the evolutionary chain of the nebulæ

just fits on to the beginning of the evolutionary chain of the stars which we had previously discussed, forming a continuous chain which now covers the whole range from nebulous matter in its earliest stages, as shown in fig. 1, down to the darkest and smallest of known stars such as Proxima Centauri.

The Structure of the Universe

The calculation of the distances of the nebulæ is of almost equal interest. Calculations made by the method just explained agree with estimates formed in other ways in assigning to the nebulæ distances of at least hundreds of thousands of light-years, ranging up probably to over a million light-years. Light travels at the rate of 186,000 miles, a distance equal to seven and a half times the circumference of the earth, in one second. The journey of sunlight from the sun to our earth is a matter of some eight minutes, that from the nearest of known stars about three years and eleven months. Thus a spiral nebula at a distance of a million light-years is something like 250,000 times as far as the nearest of the stars, which are about 250,000 times the distance of the sun, which in turn is 250,000 times as far from us as Edinburgh is from London. Of course we cannot see the nebulæ as they now are, but only as they were a million or so years ago.

The import of these figures will perhaps be better understood if we attempt, in imagination, to construct a model of the universe in which we live. The earth travels round the sun at the rate of about 20 miles a second, so that its yearly orbit is 600 million miles in circumference. Constructing our model on a very small scale indeed, let us represent this orbit by a diminutive pin-head, or by a full-stop, one fiftieth of an inch in diameter. On this scale the sun will be a tiny speck of dust and the earth an ultra-microscopic particle a millionth of an inch in diameter, while the whole of the solar system could be covered by a threepenny piece. The distance to the nearest of the stars, Proxima Centauri, will be represented by about 220 feet, while the distances of the nebulæ will be of the order of 10,000 miles. Our sun is one of a system of some 1500

Fig. 6.—Spiral Nebula in Canes Venatici ("The Whirlpool"; M. 51)

million or so of stars which form a biscuit-shaped structure bounded by the Milky Way; on our scale the size of this biscuit would be approximately that of France. The largest nebulæ would be approximately represented by Ireland, so that the sizes of these are at least comparable with that of the galactic system of stars. It is tempting to conjecture that the galactic system has been formed out of a single spiral nebula, and many attempts have been made to trace remnants of spiral structure in the present arrangement of the stars. But the discovery announced by Professor Kapteyn of Groningen in 1904, that the stars in the neighbourhood of our sun fall into two distinct streams, moving in opposite directions, has called a halt to such speculations, and it now appears more probable that our system of stars was formed by the intermingling of the stars formed out of at least two, and probably more, spiral nebulæ.

It will have been noticed that the process of the birth of the stars out of a spiral nebula is in many respects identical with the process imagined by Laplace for the birth of planets out of a nebulous sun. The essential difference between the two processes is one of scale; the spiral nebulæ are millions of times as massive, and many millions of times as large, as the nebula which Laplace imagined as the parent of our solar system. The difference of scale is so enormous that to make a body of the size of our earth visible in the nebula illustrated in fig. 7, the picture would have to be magnified to some 50 million times its present linear dimensions; it would then cover more than the whole surface of the globe.

The Origin of the Solar System

It may reasonably be asked why the same process, on a far reduced scale, cannot give birth to solar systems similar to our own. Laplace imagined three generations to exist in sun, planets, and satellites, the satellites having been born out of the planets and the planets out of the sun. Can we not embrace the whole of cosmogony by replacing this by the concept of four generations—spiral nebulæ, suns, planets, satellites? To this question observational astronomy gives no answer. Even

if suns were breaking up into planets and planets into satellites all over the sky, our most powerful telescopes are still too feeble to give any indications of the occurrence. But where observational astronomy fails, mathematical theory steps in and gives a decided negative to our conjecture. We have already mentioned various theoretical objections that can be brought against Laplace's view of the genesis of the solar system; to these may be added that even if rings or filaments of gas could be thrown off in the Laplacean manner they would at once scatter into space. It is a mere result of calculation that the colossal filaments of a spiral nebula must hold together because they are too massive to scatter into space. It is equally a result of calculation that filaments of the dimensions which would be ejected from a slowly shrinking sun would scatter into space because they would be too slight to hold together.

We must then look elsewhere for the origin of our solar system. The theory of its origin which appears able to account for most of the facts and to be open to fewest objections is the so-called tidal theory—indeed this is probably the only theory at present in the field against which quite insuperable objections cannot be brought. Just as the moon, on account of its proximity to us, raises tides on the surface of our earth, so a star passing near to our sun would raise tides on the solar surface. If the passing star continues on its course without coming too near, these tides subside and leave the sun much in its original condition. If, on the other hand, the star comes to within less than a certain calculable distance, the tidal forces become so great that the sun is literally pulled to pieces. Jets of matter are ejected, of sufficient substance to hold together without appreciable scattering into space. It can be shown that condensations would form in these jets, just as in the spiral nebulæ, and these would in all probability break up in time into detached masses of planetary size. There is, however, one noteworthy difference other than that of scale between the condensations in the spiral nebulæ and those in a tidally disrupted sun; it arises from the difference in the speed with which the process of disruption occurs. The shrinkage of a spiral is a very slow

process; century after century, æon after æon, the nebula slowly shrinks, and slowly the arms are spun out. But the tidal disruption of a star is cataclysmic in its rapidity. Its whole duration is a matter at most of a few years, possibly only of a few months. The spinning out of the arms of a nebula may be compared to the slow paying out of a coil of rope, but the tidal formation of solar jets must rather be compared to the discharge of a torpedo. The comparisons hold good beyond the mere difference in speed; the arms of a nebula must be of approximately uniform thickness, while it can be shown that a tidally ejected jet would be thickest in the middle and would taper off at its two ends. When such a jet, with its greater abundance of matter in the middle, breaks up into separate masses, we may expect to find large masses in the middle and smaller masses at the two ends. This consideration accounts quite simply and naturally for the appearance of the two most massive planets, Jupiter and Saturn, in the centre of the planetary sequence, and for the gradual falling off in mass at the two ends.

Each planet born in this way would immediately find itself under the influence of strong tidal forces from the sun, and perhaps also from the wandering star which had just disrupted the sun. In this way we can imagine the planets themselves broken up and satellites born in the process. The process cannot go on for ever; a limit is reached when the newly-born bodies are too small to hold together under their own gravitation, and calculation shows that the satellites of the planets could not give birth to still smaller bodies, or that, if they did, these smaller bodies would at once scatter into space. Indeed the smaller of the satellites now existent in the solar system can only have held together by liquefying or solidifying immediately after birth, and the same is probably true also of the smaller planets; these must at least have had a liquid centre. It can be shown that the more liquid a planet is at its birth, the less likelihood there is of its being itself broken up and forming satellites. If, however, this should happen the satellites must be larger relatively to their primary than those born out of a wholly gaseous primary. This fits in precisely with what is

observed in the solar system. The two giant planets, Jupiter and Saturn, in the middle of the sequence, are each surrounded by nine relatively diminutive satellites. Next to them come Uranus and Mars, with four and two small satellites respectively. Next again come Neptune and the Earth, each with one relatively large satellite, and beyond these Venus and Mercury, without any satellites. It seems reasonable to conjecture that Jupiter and Saturn were born either wholly or mainly gaseous, that Venus and Mercury were born largely fluid or solid, and that the Earth and Neptune were born partly fluid and partly gaseous. Mars and Neptune may well be relics of larger masses, which were born mainly gaseous but proved to be of insufficient size to hold together gravitationally until liquefaction set in.

Thus, so far back as we can trace it, we may conjecture the past history of our earth to have been somewhat as follows. Some millions of millions of years ago the atoms of which the earth and all the contents of the earth, including our bodies, are made, formed an infinitesimal fraction of a huge nebular mass, which after passing through the sequence of changes we have studied in figs. 1–7, assumed the form of a spiral nebula. This ultimately broke up, throwing off stars much as a " Catherine wheel " firework throws off sparks. One of these formed our sun, then a giant star of far greater size and magnificence than now. As the result of millions of millions of years of emission of radiation our sun has shrunk to his present moderate dimensions. Sometime during this span of millions of millions of years a wandering star came so close that our sun, unable to stand the intense tidal forces generated, broke into pieces, and out of the debris our earth and moon, as well as all the other planets and their satellites, were formed.

It is not the normal fate of a star to be broken up in this way, so that we cannot suppose every star to have our sun's accompaniment of planets. If we simplify the problem by supposing that every star is and always has been precisely like what our sun now is, and that all the stars have always been arranged and have always moved similarly to our sun's present neighbours, then there are odds of about 50,000 to 1 against a star

meeting the fate of our sun in a lifetime of 6 million million years. But this calculation greatly overestimates the odds. A star is far more liable to be broken up when it is in the earlier and more tenuous stages of its existence than when it is as compact as our sun. And the chances of break up are further increased, if, as seems likely, the stars were originally far more closely packed than they now are, and consequently far more prone to pull one another to pieces. In the present state of our knowledge it would be pure folly to try to estimate the precise chance of a star breaking up; we may, however, reasonably conjecture that planetary systems, although not the normal accompaniment of a sun, must be fairly freely scattered in space.

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The development of the subject has been so rapid in recent years that large parts of some of the above books are already out of date. The most modern results and opinions are to be found only in recent volumes of scientific journals and of the publications of learned societies, especially:

Monthly Notices of the Royal Astronomical Society.

Nature.

The Astrophysical Journal.

CHAPTER II

The Evolution of the Earth as a Planet

In the previous chapter of this book Dr. Jeans has given an account of a theory of the origin of the solar system. In the present chapter I shall deal with the development of the earth from its earliest stages up to the present time so far as they can be inferred from the theory adopted for the origin of the earth, but supplemented where necessary by reference to the present state of our system. It would probably be too much to expect of any cosmogonical theory that it should predict everything about the earth without occasional supplements from other sources on points of detail; the best that can be expected is that it should predict more facts than it assumes, and in this respect the theory comes well up to requirements. It does not seem possible to confine the discussion entirely to the earth, chiefly on account of the large amount of information about the earth that emerges in discussing its satellite, the moon, whose birth and subsequent history alike have had most important reactions on the parent body. Thus a considerable amount of attention will have to be paid to the moon; in addition, the planet Mercury provides one important piece of information that has no precise analogue within our own subsystem, and therefore must be considered.

The gaseous filament drawn out of the sun by the passing star, postulated by the tidal theory, broke up into separate nuclei almost as soon as it was formed. Each nucleus then proceeded to revolve about the sun as an independent planet. In being pulled away from the sun the matter acquired a considerable radial velocity, and when the star withdrew a large fraction of

this velocity would presumably be retained. Thus the primitive planets did not revolve in circles about the sun, or even in ellipses differing but little from circles, as at present; they moved in fairly long ellipses. Their mean distances were not very different from their present values. They were so hot as to be wholly gaseous, and accordingly they were very much distended in comparison with their present sizes.

Early Changes in the System

The first striking change in the system from this state was the formation of the satellites of the great planets. When the larger nuclei passed perihelion for the first time after they were formed, the sun was able to produce large tides in them, and caused them to eject filaments in the same way as the sun itself had done a few years before. These smaller filaments broke up in just the same way as that sent out from the sun; thus the satellites were formed. The early history of the smaller planets was more complicated. When a portion of a gas is suddenly released in a practical vacuum, as happened in the case of the primitive planets, it tends to spread out; this process could cease completely only when the matter had spread throughout the whole solar system. But in the case of the planets two factors were available to restrain this diffusion. First, the gravitation of the nuclei would tend to pull back any wandering molecules; second, much of the matter would liquefy, and when this took place the liquid drops would travel outwards much more slowly than the outer boundary of the gas. It can be shown that if the primitive sun was gaseous its radius cannot have been more than twenty million kilometres, say a third of the mean distance of Mercury from the sun; its density would then be 0·00005 of that of water. A gaseous mass of this density, composed of the vapour of silicon, one of the earth's chief constituents, could hold together by its own gravitation if its mass was somewhat greater than the present mass of the earth, but not if it were less than this value. The critical mass would be less if the primitive sun was smaller and denser than has just been supposed; but however small

the sun may have been, it can still be shown that no solid body whose radius in the solid state is less than 1400 km. could have held together in the gaseous state. Many satellites, and all the asteroids, fall short of this limit, and it therefore appears that a large number of the bodies in the solar system were not formed by slow condensation from the gaseous state. A different mechanism must therefore be sought for all bodies smaller than the great satellites of Jupiter and Saturn, and it may have affected considerably even a body as large as the earth.

The four great planets then proceeded to cool slowly, and gradually became liquid and then solid. In the smaller bodies the tendency to flow out would give rise to velocities so great that the small gravitative power of these masses could not prevent the escape of the outer portions; thus they necessarily lost a good deal of their mass, especially of their lighter and more volatile constituents. Such an expanding body, however, would fall rapidly in temperature. It is well known that the temperature of a gas can be raised by sudden compression, as can easily be verified by pumping up a bicycle tyre quickly and observing how hot the pump becomes around the nozzle; and, conversely, rapid expansion is the chief part of the process for making liquid air. Both for this reason, then, and also on account of radiation from the surface, the expanding body would become colder, and would proceed to form liquid drops. This part of the process would take a very short time, probably not more than a few days. The liquid drops would move outwards much less rapidly than the front of the gas, and gravity might be able to control the motion of a large fraction of them. Each drop would then fall slowly towards the centre of the body. A liquid drop surrounded by gas would necessarily be heated, or at any rate not cooled, and therefore it would still be liquid when it arrived at the centre. Thus a liquid core would accumulate. The result of the condensation would thus not be very different whether the nucleus considered had more or less than the critical mass. Every mass would in time begin to form a liquid core. The larger nuclei would, however,

take a longer time before they commenced to form cores. The earth-nucleus probably began to form one within a few hours or days of leaving the sun, and it is practically certain that the smaller planets and satellites did so. Jupiter, on the other hand, would not be subject to the same rapid expansion as the smaller bodies, and cooled in a more leisurely fashion by radiation from the surface. The smaller bodies lost much of their material, especially of their lighter constituents, whereas the great planets retained practically the whole. It is possible to account in this way for the fact that the great planets have much smaller densities than the smaller ones. Jupiter, then, may have existed as a gaseous mass for thousands of years before it condensed to any appreciable extent. The earth and the other terrestrial planets, on the other hand, lost their lighter materials at once, and had begun to form liquid cores before they passed perihelion for the first time. Hence they had by this time increased considerably in density. Now the distance within which a nucleus would have to approach the sun in order to be broken up is closely connected with its density. A nucleus whose mean density was equal to that of the sun would be broken up if its distance from the centre of the sun was less than about twice the radius of the sun; but it could survive actually grazing the sun's surface if its density was fourteen times that of the sun. It is extremely probable, from consideration of the way the early nuclei would develop, that the densities of all the four inner planets had come to exceed this value before they passed perihelion for the first time. Thus the gravitational attraction of the sun was insufficient to break them up and make them develop retinues of satellites. The moon and the two satellites of Mars have probably had very different histories from the satellites of the great planets.

The earth, when it had passed the turbulent period of its earliest youth, proceeded to cool down till it was completely liquid. Just how long this took is uncertain; we have sufficiently definite knowledge about its initial temperature, size, and power of radiating heat away to be able to say that it must have been completely liquid within 5000 years of its formation;

but the actual time was probably very much shorter. Solidification would take rather longer, since by that time the temperature would be lower and the radiating surface smaller, thus reducing the rate of loss of heat by radiation in two ways. The time of solidification might have been as long as 10,000 years. Thus the earth was mainly solid within 15,000 years of its formation.

Birth of the Moon

At some stage during this process the moon was formed. The moon is in many ways a very exceptional satellite. It is the fourth most massive satellite in the solar system, the only heavier ones being two of those of Jupiter and one of those of Saturn. It is far the densest satellite; its specific gravity is 3·6, as against 1·5 for the densest of the three others just mentioned. Its mass is $\frac{1}{81}$ of that of its primary, whereas no other satellite has a mass as great as $\frac{1}{4000}$ of that of its primary. Its high density forbids its having been formed from any of the great planets. It must therefore have been formed from the earth. But if it was formed from the earth by tidal disruption while gaseous, it would have resembled the planets themselves and the satellites of the great planets in being very small compared with its primary. On the other hand, ordinary tidal disruption of a wholly or largely liquid earth would be impossible, for a reason already given, namely that the density could hardly have been less than 5, while that of the sun must have been more like 0·00005. Thus the density of the earth would have exceeded that of the sun so much that the tidal action of the sun could not have broken the earth up, however closely the earth approached the sun. Thus there seems to be no way of accounting for the formation of the moon.

There remains, however, a further alternative. It is possible that a combination of circumstances may be able to accomplish what none of them could do singly. The earth is rotating and the moon is revolving about it. Suppose that they were formerly one body, but that by some interaction between them (let us not consider at present what) the moon has been made

to recede to its present distance. Given the present rate of rotation of the earth and the period of revolution and mean distance of the moon, it is easy to calculate what must have been the period of rotation of the combined body. It turns out to be very nearly four of our present hours. A body of the mean density of our earth, rotating in such a period, would bulge around the equator much more than at present. The difference between the lengths of two diameters of the earth, one in the equator and the other joining the poles, is about 40 km.; the difference in the primitive earth must have been about 1440 km. Great as this polar flattening is, however, the earth could have held together when rotating in four hours if no external factor complicated the situation. Such a factor was, however, introduced by the small tidal action of the sun. Suppose for a moment that we have a pendulum whose length is adjusted so that it beats exact seconds, and suppose we give it a series of very small pushes at equal intervals. In general the only effect will be that the pendulum will swing. However many times it is pushed, it will never oscillate through more than a definite range, depending on the violence of the pushes and the interval between them. But if the interval between the pushes is exactly a second, so that the pendulum is pushed every time it passes the lowest point in the same direction, there is no limit to the extent of the swings that may be gradually worked up, even though each individual push may be quite gentle. This is, of course, the principle used in the ordinary swing. This method can be applied to any system capable of executing small oscillations; all that is necessary is that the disturbance must have the same period as the system left to oscillate by itself. Now a fluid planet could oscillate in such a way that the polar axis kept constant, while two axes at right angles in the equator alternately became longer and shorter, the equator at any instant being an ellipse. The time it would take any particle to move in and out again can be estimated fairly closely, and it appears that for an earth rotating in four hours this time would be very near two hours. But the solar tidal action would pull each particle of the body outwards

twice in each rotation, as at present. Thus the conditions in the primitive fluid earth were analogous to those of the pendulum considered above. Hence every time the earth rotated the oscillation would become greater and greater in extent. When it became great enough, which would probably happen when the longest axis was about two or three times as long as

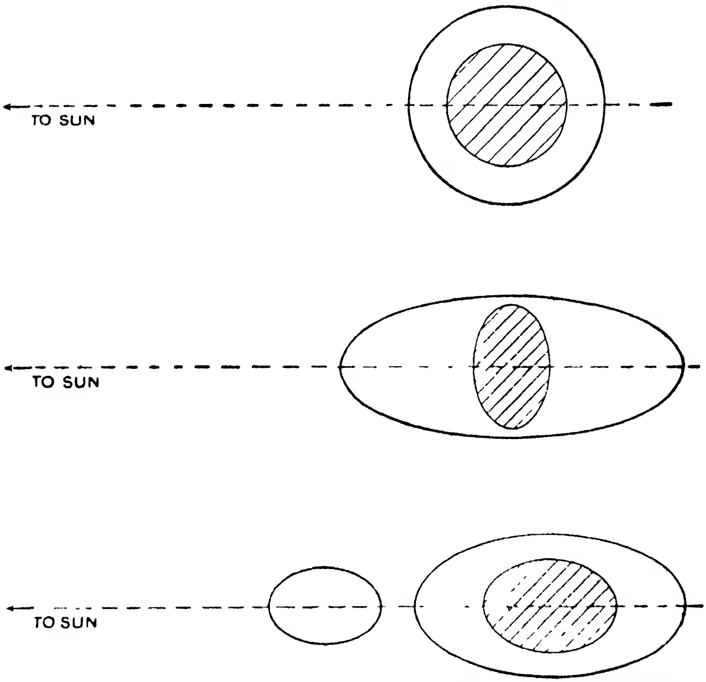

Fig. 1.—Successive Stages in the Formation of the Moon. The Shaded Region is the Earth's Metallic Core.

the shortest, it would be impossible for the earth to hold together any longer, and one end would separate off. The detached fragment became the moon.

The possibility of this mode of origin of the moon rests entirely on a curious numerical coincidence. It just happens that the earth and moon, when combined into one liquid mass, would rotate at the rate needed to make the natural period of

an oscillation of tidal type equal to the period between successive high tides raised by the sun. There is no prior reason that we can see why it should be so; but it does appear from the present state of the system that it was so. When all other suggested theories have failed, and the surviving one is supported by such a coincidence, it is necessary to take it very seriously.

On this theory the moon must have been formed while the earth was mainly liquid. When it was gaseous it would be too distended, and would rotate too slowly to give the requisite agreement; when much of it had become solid the rigidity of the solid part would make it vibrate in a shorter period than two hours, and again the agreement would break down. It is therefore necessary that the formation of the moon took place while the earth was liquid.

When the earth was on the verge of solidifying, therefore, it was moving around the sun in a highly elongated orbit, attended by a moon also on the verge of solidifying. The distance of the moon from the earth was much smaller than at present, probably not more than two or three times the earth's radius. We have to trace how the earth's motion came to be altered till its orbit was nearly a circle, and how the moon came to recede till its mean distance was about sixty times the earth's radius, as at present.

How the Orbits became nearly Circular

The whole of the solar system was filled with a thin gaseous medium, consisting of the parts of the original filament that had escaped from the influence of the nuclei by diffusion and expansion, instead of being absorbed into them. The primitive planets, in revolving around the sun, had to force their way through this gas. The gas itself was not at rest; any matter, even gaseous matter, initially at rest in the solar system, would have fallen straight into the sun and been absorbed. Each part of it must, after a few violent oscillations at the beginning, have come to move in a nearly circular path about the sun, with a velocity nearly equal to that of a planet moving in a

circular orbit at the same distance from the sun. A planet moving in an orbit differing from a circle, however, would always have a motion relative to the medium. When it was receding from the sun the resistance of the gas would be pushing it back towards the sun; when it was approaching the sun the medium would be pushing it outwards. Thus the medium would tend to reduce the in-and-out motion of the planets and make their orbits more nearly circular.

How long, then, would it take before such a medium reduced the eccentricities of the planetary orbits to their present values? The question can be answered roughly by considering the planet Mercury. Its eccentricity is at present about a fifth; on the tidal theory of its origin it was initially nearer four-fifths. We do not know directly either the time taken or the density of the medium, but the total effect on the eccentricity of the orbit of Mercury is a calculable multiple of their product. Hence their product can be found. Again, the medium must have had time to disappear almost completely by diffusion and viscosity, leaving only a faint remnant to produce the zodiacal light. The time needed for this turns out to be proportional to the density. Thus the ratio of the time to the density can be found. Thus we can find both the ratio and the product of the age of the system and the initial density of the resisting medium, and hence we can find both the age and the density separately. It is found that the time taken was probably between a thousand million and ten thousand million years; the initial mass of the medium was comparable with that of Jupiter. Unfortunately the argument has not yet been applied to any planet other than Mercury; all planets would produce by their gravitation condensations of the medium around them, and except in the case of Mercury, for which this effect would be inappreciable, it is not yet known to what extent these condensations would affect the resistance.

The Solidification of the Earth

Let us now return to the conditions a few thousand million years ago, and consider what changes would take place inside

the earth itself after it became solid. The formation of a solid crust would have an immediate effect on the rate of cooling of the interior. So long as the earth was fluid and cooling by radiation from the surface, any matter cooled on the surface would become denser than that just below, and would sink. Thus the interior of a fluid earth would be in a state of continual agitation, and the heat of the interior would be carried to the surface by means of convection currents as fast as it could be radiated away. When a crust was formed, however, heat would reach the outside only by conduction, which is a much slower process. For instance, if the crust was a kilometre thick, and the matter just inside it was 1000° C. hotter than the outside, conduction could only carry heat to the outside at the rate of 0·00005 calorie per square centimetre per second. The sun's radiation supplies heat at a rate of 0·03 calorie per square centimetre per second. Hence even at a very early stage of solidification the sun's radiation would overwhelm the heat conducted from the interior, and thus the outside temperature would be controlled almost entirely by the sun. It therefore fell rapidly from the melting-point to whatever temperature the sun was able to maintain. Now the total radiation of a star depends on its mass, and on little else, and the sun's mass can hardly have varied much since the earth was formed. Thus its total radiation cannot have differed very much from the present value. The earth's surface temperature, therefore, has been nearly equal to its present value almost ever since a solid crust formed. Thus if there was any water in the atmosphere before solidification started, it would condense to form oceans almost as soon as a solid crust was formed. The rain at that time would be much heavier than anything we know now; a hundred inches of rain might fall in a day.

When first there was a solid crust on the earth, wholly or partly covered with water, denudation could occur, and geological time began.

The cooling of the crust from the melting-point of rocks down to ordinary temperatures would make it tend to contract

violently. This would prevent it from continuing to fit the still uncooled interior, and fractures, followed by a complicated series of other changes, would set in. The present appearance of the surface of the moon, with its chain of large smooth maria, probably produced by the outflow of lava from the interior, its streaks, and its craters, may serve as a clue to what happened; but it is only a clue and not a solution, for matters on the earth were further complicated by the presence of an ocean, which the moon never had.

Mountain Building

This stage over, the outside had no more cooling to do; but the inside went on cooling and contracting. Thus the outside was left partly unsupported on its inner boundary, and had therefore to support itself by its own strength like an arch. But there is a limit to the stress of this kind that a material can stand, and after an interval of perhaps fifty million years the outer layers gave way. They crumpled up irregularly along their lines of weakness, and collapsed on the interior. Then the process recommenced, and another stage of crumpling ensued. It seems likely, both as a result of calculation and of geological observation, that about six great periods of crumpling have occurred up to the present time.

This mechanism of gradually growing stresses, relieved at intervals by crumpling, constitutes the thermal contraction theory of mountain formation. It is an old theory, and was for a long time thought to have been proved inadequate to account for any large fraction of the mountains that actually exist. The discovery of radioactivity, however, has shown that the earth is much older than was formerly believed, and has made it possible to reconcile theory with observation. It seems that the compression available on the thermal contraction theory and the compression needed to account for all the existing mountains are probably about equal (a few million square kilometres, the whole area of the earth being 520 million square kilometres), and certainly of the same order of magnitude.

Thus in any case thermal contraction must be a major cause of mountain building. No other theory that has been suggested as an explanation has survived quantitative comparison with the facts, and therefore the presumption is that thermal contraction accounts for almost the whole of the mountains on the earth.

Geological Time

Radioactivity affords a valuable aid in another great problem of geophysics. It gives us the best means we have of determining long intervals of geological time. The element uranium is present in a large number of minerals that occur in igneous rocks. Now in any sample of uranium the atoms are continually breaking up; and each atom, when it has undergone its first disintegration, continues to split up again and again. The final result is that one uranium atom gives one atom of lead and eight atoms of helium. But in addition we know the rate of break-up of uranium; in a sample of uranium one atom in every seven thousand million breaks up every year. Suppose then that we have a chemical analysis of a uranium-bearing mineral. The amount of lead present tells us how many uranium atoms have broken up since the mineral was formed; we know the amount of uranium still there, and therefore, by simple addition, the amount that was there originally; thus we can find what fraction of the original uranium has broken up. But since we know how fast the uranium breaks up this tells us at once the age of the mineral. By this method the ages of minerals of many geological periods have been found. The oldest known are some Canadian rocks, whose age since crystallization turns out to be about 1400 million years. They are intrusive rocks, which have been injected into still older conglomerates, which must themselves have been derived from older igneous rocks. The age of the earth is then at least a geological period greater than 1400 million years. It is of interest to note that this estimate comes within the limits of age indicated by the eccentricity of the orbit of Mercury.

The Tides

The moon, when first formed, was at a distance of about 1·2 times the earth's diameter from the centre of the earth. Its present mean distance is about thirty times the earth's diameter. Now the square of the moon's time of revolution would be proportional to the cube of its mean distance; thus the period of revolution would be about five hours. The earth's period of rotation would be a little shorter. In addition the moon would raise tides in the ocean, as at present, but the tides would be very much larger than any we know of now. The height of the tides is inversely proportional to the cube of the moon's distance. Thus when the moon was at a twenty-fifth of its present distance the tides would have about 15,000 times their present height. Now at present the height of the tide in mid-ocean is about 25 cm. This is not the result of direct observation but of calculation; nobody has yet succeeded in measuring the tide in the open ocean directly. Thus the height of the primitive tides would be about four kilometres. This gigantic wave would travel steadily round the earth, swamping every hill and continent in its track, if there were any hills and continents at that time. It would be the most formidable agent of denudation in the whole history of the earth, and it probably had a considerable influence in determining the distribution of land and sea. At low tide the surface of the water may have been depressed so much that the ocean bottom was left dry, the whole of the water on the earth chasing around steadily after the moon.

This state of affairs clearly could not last. Water flowing over a solid bottom always produces a certain amount of friction, and friction necessarily implies a gradual loss of energy. There would, indeed, be some resemblance between the earth and moon and a pair of fly-wheels connected by a slack belt. If the belt were not there, the fly-wheels could go on rotating indefinitely, each behaving independently of the other. But when the belt connects them its friction gradually changes their motions, the velocities of points on the edges of the two wheels

becoming more nearly equal. In the case of the earth and moon some mathematical discussion is necessary before we can find out just what effect friction would have. It turns out that it would make the earth rotate more slowly, the tides acting as a brake on it, while the moon would be driven away from the earth. The rate of recession would be large at first, but it would diminish rapidly as the distance increased and the tides became correspondingly smaller. It is still going on; and it will not stop until a stage has been reached when the earth's period of rotation and the moon's period of revolution have been made equal. Then both will be about forty-seven of our present days, and the earth and moon will keep the same face permanently turned towards each other.

The present rate at which the moon is receding from us is capable of being found by observation. Given the present lengths of the day, month, and year, it is possible to predict accurately the time of, say, an eclipse of the moon. Alternatively, we can find the time of a past eclipse, even thousands of years ago. Now such eclipses were observed by the astronomers of those ages, and it is found that there is a systematic difference between the calculated and observed times; for eclipses 2000 years ago the discrepancy amounts to about an hour. This can be attributed only to changes in the angular velocities. Now the theory of tidal friction enables us to find the ratio between the change in the moon's angular velocity about the earth and that of the earth's rate of rotation. The discrepancy in the times of eclipses therefore gives us the additional datum required to determine both rates of change.

The rate of change in the length of the day thus found is very small; it takes 120,000 years to lengthen the period of the earth's rotation by one second. Nevertheless it implies that the change in the long intervals indicated by the geological record has been considerable. Supposing that tidal friction has always operated at the same rate, we find that 1400 million years ago, when the oldest known igneous rocks were formed, the earth must have rotated in 0·84 of our present days. Taking the calculation farther back still, we find that the complete

series of changes from the moon's formation to the present state could be brought about in 4000 million years. This rests, of course, on a supposition of uniformity, and is therefore subject to modification according to the conditions of past eras. What is important is that this estimate of the age of the earth is of the same order of magnitude as those derived from other sources.

The attribution of the changes in the angular velocities to tidal friction has been verified directly. Given the observed discrepancies in the eclipse times it is possible to calculate how fast the system must be losing energy to produce them. It amounts, on an average, to $1{\cdot}4 \times 10^{19}$ ergs (i.e. 14 trillions of ergs) per second. It seems probable that the whole of this loss can be attributed to the friction of the tidal currents in shallow seas. The chief sea in producing the effect is the Bering Sea, but important contributions are made by the Yellow Sea, Malacca Strait, the Irish Sea, and the English Channel. The total rate of loss of energy in the seas yet investigated is about $1{\cdot}1 \times 10^{19}$ ergs per second, in sufficiently close agreement with the dissipation needed to explain the eclipse observations. Other seas not yet investigated may make small contributions, which will make the agreement better, but in any case the outstanding difference is within the uncertainty of the observations.

Tides in the open ocean contribute little to the dissipation of energy. The rate of dissipation is proportional to the cube of the velocity of the current, and the currents in mid-ocean are very small, probably not exceeding 1 cm. per second. In the shallow seas the velocity ordinarily reaches about 100 cm. per second, so that the rate of dissipation per unit area is a million times as great. This factor is much more than enough to compensate for the limited area of the seas.

The Age of the Earth

It seems to be unlikely that any other method yet suggested for determining long intervals of geological time is comparable in accuracy with that based on the rate of production of lead from uranium. There is no reasonable doubt about the rate of

disintegration of uranium, or about the nature of its final product; the chemical analysis of the minerals containing uranium can also be done with as much accuracy as one could wish. The only grounds for uncertainty are first, whether the minerals contained any lead when they were first formed, and second, whether they have been altered in any way by external agencies since they were formed. These points can be decided only by reference to the individual cases themselves. Uranium minerals as a matter of fact are usually very tree from lead when they are first formed; the great chemical differences between the two elements prevent their compounds from crystallizing together. In case of doubt, another test can be applied, which is decisive; this is to determine the atomic weight of the lead present. Ordinary lead has an atomic weight of 207·1, but the lead formed from uranium has atomic weight 206. Thus if any appreciable quantity of ordinary lead was present from the start the atomic weight of the lead in the mineral would be found to be above 206, and its presence could be discovered. Original lead, however, does seem to forbid the use of the other plentiful radioactive element, thorium, in determining geological time. Theoretically thorium ought to yield as its final product a lead with atomic weight 208; but samples of lead actually found in thorium minerals have nearly all been found to have lower atomic weights, between 207 and 208, and there seems to be little doubt that the differences are due to the presence of original lead, differing in quantity from specimen to specimen. There is a certain amount of chemical resemblance between lead and thorium, which may have made the partial replacement of thorium by lead easier than that of uranium. In any case it is found that when ordinary geological methods indicate that two uranium minerals are of the same age, the uranium-lead ratio is found to be the same except when the mineral has been altered since formation, while the thorium-lead ratio in thorium minerals of the same age is found to be highly variable.

The second proviso, that the mineral must not have been altered by external agencies since it was formed, is easily seen

to be necessary. Alteration by heat promotes recrystallization; thus the constituents are redistributed among the minerals of the rock, and the analysis of a single mineral ceases to give the quantity of lead that has actually been produced by the uranium originally present. Alteration by water or air, or both together, acts in the same way, while some of the constituents are dissolved and washed away altogether. Fortunately geologists know how to recognize when a mineral has been altered, so that errors from this source can be avoided. There are enough trustworthy determinations to make it possible to discard the unsatisfactory ones.

The other two methods of estimating the age of the earth that have been mentioned above evidently give only the order of magnitude. The argument from the eccentricity of the orbit of Mercury is not accurate, on account of the uncertainty in the original distribution of density in the resisting medium. This is very unlikely to have been such as to make the argument give a wrong estimate of the order of magnitude of the age of the system, but it makes a precise calculation impossible. The argument from tidal friction also is subject to uncertainty, since it has been seen that most of the friction takes place in shallow seas. These seas are just the places that are most affected by geological changes; a reduction of 200 metres in the depth of the ocean would convert into dry land any of the shallow seas where most of the dissipation of energy is taking place at present. Thus the shallow seas that produced most of the effect in past eras were not those that produce it now. Tidal theory is not yet in such a state that we can calculate the tidal currents in the open ocean *a priori* for any given distribution of land and sea, and consequently we cannot find the tidal friction at any time past; the best we can do is to suppose it the same as at present, apart from a factor to allow for the effect of the change of the moon's distance. Thus this method also gives only an order of magnitude and no more. But a method giving only an order of magnitude is not for that reason unimportant. It has two uses; it serves as an additional empirical check on a method, such as the uranium-lead ratio

method, that seems from theoretical considerations likely to be more accurate, and it rules out as incorrect any theories that would require ages of the earth of different orders of magnitude. On the argument from tidal friction alone, for instance, it would be possible to reject any theory that made the age of the earth less than a hundred million or more than a hundred thousand million years; and though these limits are wide, estimates have been given, on evidence requiring serious consideration, that lie outside of them on both sides.

Only one other set of methods need be mentioned here, namely those depending on denudation. The principle of all of them is that if we can find the rate of transfer of some substance to the sea in rivers at the present time, and also the total amount of the transfer since denudation started, the ratio should tell us how long denudation has been acting. They depend fundamentally on the assumption that the present rate of denudation is equal to the mean for all geological time. There is strong reason, however, to believe that this is not the case. A great period of mountain building has recently, comparatively speaking, raised the mean level of the land to far above its usual value, thus accelerating denudation, and over a large part of the earth's surface denudation has been rendered especially easy by a recent glacial period. Thus these denudational methods would be expected to give too low values for the age of the earth. This actually turns out to be the case; they usually give about 300 million years when proper allowances have been made for the fact that some matter on the way to the sea has been there before. But the proper interpretation to put upon them is that the present rate of denudation is about five times the average of the past.

Continent Formation

Some of the most difficult questions in geophysics to answer remain to be discussed. We have some idea about how mountains were formed, but hitherto no theory of the formation of continents has survived examination. We know that the ocean is older than the oldest known igneous rocks, because

there are sedimentary rocks older than these; but is there in fact about the same amount of water on the earth now as there was originally, or has it increased very much during geological time? Indeed, is the atmosphere itself an original appendage of the earth, or has it, like the igneous rocks themselves, been formed from the earth's interior during geological time? None of these questions has yet received a satisfactory answer, but they are of such importance that a discussion of some of the principal attempts to reply to them is well worth while.

The best known theory of the origin of continents is probably the one connecting it with the origin of the moon. While the fluid primitive earth was being drawn out to make a much magnified solar tide, the two ends of the mass, pointing towards and away from the sun respectively, would be almost exactly alike. Whatever it was that determined which end it actually was that broke off, it must have been some factor quite subsidiary in magnitude to the main tidal forces. But the rupture itself introduced a great difference between the ends. According to the theory under consideration, this difference is preserved to this day in the distribution of land and sea, the Pacific Ocean being the scar left where the moon had been torn off.

It is seen that this theory involves several hypotheses in addition to the postulated theory of the origin of the moon, which by itself seems to be very probable. Clearly there could be no question of the moon having left a scar if the earth was wholly fluid at the time; the fluid would at once fill up the hole and efface every trace. Thus the theory requires that solidification had begun when the moon was formed. This introduces several fresh considerations, for we have seen that the theory would not work if the earth was wholly or largely solid, since the natural period of oscillation of a solid earth would be much shorter than the half-period of rotation, probably about twenty minutes as against two hours. The solidification cannot then have proceeded to such an extent as to affect the earth's natural mode of vibration appreciably. At the most a thin crust could have formed on the surface. Now let us consider for a moment

the nature of the motion of the materials of the earth at the time. The projections were permanently under and opposite to the sun respectively; thus the outer boundary of the mass was only rotating slowly, in about a year. But the actual matter was in rapid motion; the liquid was swirling round within the boundary once in every four hours, just as we can make water revolve steadily within an elliptical dish, even though the dish itself may be at rest. It seems likely that any solid crust, distorted by tidal action into so elongated a form as the theory requires the outer boundary to have taken, must have been shattered to fragments in the process; but even if it were not, it would certainly be shattered during the violent oscillations (with a period of about two hours, be it remembered) that followed the rupture. Thus the moon's departure would leave a number of solid fragments, perhaps of continental dimensions, but probably a good deal smaller, floating on the surface of an otherwise fluid planet. Now these fragments would not stay where the moon left them. A heavy mass of fluid left to itself tends to arrange itself so as to get the heaviest materials as close together as possible, or, what is the same thing, so that the lightest materials will be as far apart as possible, leaving the most central portions for the heavy ones. In this case the lightest materials are the solid blocks, which would therefore spread themselves out so as to make their mutual distances as great as possible; thus, like a party of shy people who have not been introduced, they would settle down at approximately equal distances. The blocks would therefore be distributed nearly symmetrically over the earth's surface. The marked asymmetry shown in the fact that the Pacific Ocean occupies half the earth's surface, while nearly all the land is crowded into the other half, therefore remain unexplained.

Various attempts have been made to modify the theory so as to make it work, but all seem to meet new difficulties. It is natural to suggest, for instance, that the fluid part of the earth may have been already highly viscous, and therefore that it may have taken the solid fragments so long to spread out that the remainder of the earth was solid before they had spread

far. This, however, is too high a degree of viscosity to be admissible. If it could have so great an effect as this, it would have had an important damping effect on the tides; however accurately the periods were adjusted, a large oscillation could never be worked up if any important amount of friction were available to influence the motion. Thus the condition for the theory to account for the Pacific Ocean makes it impossible for the theory to account for the moon; as with Gonzalo's commonwealth, the latter end of the argument has forgotten the beginning.

A less ambitious theory, though a less clearly unsatisfactory one, is the Tetrahedral Hypothesis. This is based on a slight resemblance to a regular tetrahedron shown by the solid body of the earth. The four vertices of the tetrahedron are supposed situated in the Antarctic Continent, North America, Europe, and Central Asia. The suggested explanation is that, when the newly solidified outer crust first became subject to compression on account of the contraction of the interior, it tended to adjust itself by taking the form of the regular solid with the largest surface for a given volume, thus accommodating the old surface to the new volume in the most effective way possible. This solid is the regular tetrahedron. There seems to be some empirical foundation for the belief that such circumstances do introduce a tendency to a tetrahedral form; at any rate a partly deflated football bears some resemblance to a tetrahedron. The theory has not yet been subjected to quantitative examination, but it seems probable that gravity would introduce serious modifications into it. The four projections, if produced, would involve great variations in the pressure of the fluid on the interior of the solid shell, tending to restore the spherical form. It seems likely that in a thin crust these would produce greater stresses than the strength of the material could support, and that the impasse could be relieved only by fracture of the crust. Thus ranges of mountains, and not gently rising elevations of continental extent, would be produced. In any case the tetrahedral theory can be only a partial explanation of the distribution of land and sea; it does not pretend to explain the

Pacific Ocean, which is certainly the most striking feature of this distribution.

It seems to me possible that at any rate some aspects of the formation of continents will have to be brought into relation to the changes that took place in the earth after the moon had been detached and a thick solid crust had been formed. The effects of the cooling of the crust from the melting-point down to ordinary temperatures have already been mentioned. A honeycomb of vertical cracks would be formed in the crust, and the further the cooling proceeded the deeper would these cracks become. At the same time the parts of the surface between the ends of the cracks would have to support the whole of the tension; and thus they would give way, the cracks gradually extending horizontally until the whole crust was broken up into a system of large detached blocks of continental dimensions. If the cracks penetrated the region where only slight cooling had taken place, fusion under relief of pressure would take place, and the magma would pour up through the cracks on to the surface. The great series of maria on the moon are possibly instances of such an outpour.

The Earth's Ellipticity

The change in the speed of the earth's rotation must also have had an important influence on its surface features. Everybody who has ever whirled a heavy object around on the end of a string has noticed that a tension in the string is necessary to keep it going; if the string is cut or broken it flies off along a tangent. The mass of the body and the length of the string remaining the same, the tension required is inversely proportional to the square of the time of one revolution. Now in the earth every particle is revolving steadily in a circle about the polar axis, and this motion in the same way can be maintained only if there is a force perpendicular to the axis and inversely proportional to the square of the period of rotation. This force is supplied by the earth's bulge around the equator. The gravitational attraction of a spheroidal mass on a particle outside it is not quite towards its centre. The attraction on

a particle at the surface, indeed, is not perpendicular to the surface, but lies between the downward perpendicular to the surface and the line joining the particle to the centre. It therefore tends partly to move the particle downwards, a tendency balanced by pressure, and partly to move it along the surface towards the axis. The latter component provides the force necessary to maintain the steady rotation. We should therefore expect the difference between the earth's polar and equatorial axes to be inversely proportional to the square of the time of rotation, a result confirmed by more precise calculation. Now at present the ratio of the axes is 296/297, a statement usually expressed by saying that the ellipticity is 1/297. Thus when the earth rotated in five hours its ellipticity must have been 1/13. The volume being nearly the same, the equator must have been longer than at present by one part in 39, while the polar axis must have been shorter by one part in 19. Thus the change in the speed of rotation since the moon was formed must have resulted in the compression of the equator by over 1000 km., a greater compression than is indicated even by the thermal contraction theory. Most of this compression, however, is probably not available to account for existing mountains, because it was developed very quickly after the moon was formed, and the greater part of it may have occurred before the oldest known sedimentary rocks were laid down. If, for instance, tidal friction has operated at its present rate since the oldest known igneous rocks were formed, the compression produced by change of rotation during that time would be only 14 km., an appreciable correction to other estimates, but not enough to be regarded as a main cause in itself.

In another way, however, the effects of change of rotation may be extremely important. The change of ellipticity implies not only compression around the equator, but also tension across the poles. Thus an extensive series of large fractures would be produced in polar regions. The heavy magma from the interior would flow out through these, and, depressing the crust by its weight, would make basins which would now be occupied by oceans. It is natural to connect this effect with

the fact that the North Pole is actually in the middle of an ocean, while the South Pole is surrounded on every side by extensive oceans. Some writers have seen an obstacle to the belief in any considerable change in rotation in the fact that there is land actually at the South Pole; but in emphasizing the Antarctic continent while overlooking the vast oceans in high latitudes that surround it, they seem to me to strain at the gnat while swallowing the camel. The theory would not, of course, imply that a large continental block originally there should move away when the outflow took place; that would require some special force which is not indicated by the theory. All it implies is that large fractures and oceans should occur in high latitudes, which is the case in both hemispheres. The difficulty in the theory, as in all others relating to continent formation, is that it does not explain the concentration of land in middle latitudes in the northern hemisphere, or of water in the Pacific.

The great tides raised by the moon in its early stages may themselves have been a not unimportant factor in determining the primitive distribution of land and sea. Even the small tides we have at present play an appreciable part in denudation near the shore; what effect a tide 4 km. in height on an average could have had it is difficult to imagine. That it must have been an important agent in denudation is certain. But in addition we may remember an important property of water in motion—its tendency to flow with special rapidity in an already existing deep place, and thereby to deepen it still further. It is tempting to suppose that some originally slight difference of elevation between the northern and southern hemispheres was in this way magnified by the primitive tide until it gave the present great difference of level; but whether this is a tenable proposition cannot be decided without a great deal of investigation.

The Moon's Rotation and Figure

In case the account so far given of the formation of the moon and of the physical process that has led to its withdrawal

to its present distance may seem to have taken us rather far from our data, it is desirable to call attention to some features of the moon that give a striking confirmation of it. While the moon raises tides in the earth, the earth raises much larger tides in the moon. While the moon was producing an appreciable change in the rotation of the primitive earth, the earth produced a much greater change in the rotation of the moon; it damped it down till the moon was brought to keep the same face permanently turned towards the earth. Then the tide in the moon was always on the same part of the moon's surface, and there was no occasion for tidal friction to produce further changes. This state is preserved to the present day; this is why the moon always keeps the same face to the earth. The chief difference is that the moon has no water on its surface; the friction took place in its interior and not in shallow seas.

But this point by itself only shows that the moon's rotation is adapted to its present distance; it gives no indication of the moon's past. There is, however, a feature of the moon's figure that does give such an indication. Given the distance of the moon from the earth when it solidified, we can find what the height of the tide raised by the earth must have been. If only the matter that constitutes the moon is strong enough, it may have retained the form it took at that time. Now this is actually the case; the moon has a motion that indicates quite clearly that it is elongated towards the earth about sixteen times as much as if it had solidified at its present distance. This elongation is, however, consistent with the moon's having solidified when at only about a third of its present distance from the earth. Thus the figure of the moon shows a fossil tide, recording its former proximity to the earth, raised by the earth over 1000 million years ago, and retained ever since by the sheer strength of the rocks that make up our satellite.

It may be remarked that the height of this petrified tide is just about a kilometre. This amount is much greater than the corresponding quantity for the earth, not only relatively but absolutely. We have seen that the earth probably had originally a much greater ellipticity than at present, but that in con-

sequence of the weakness of its materials it has repeatedly adjusted itself to changes of rotation. Actually the difference between the ellipticities of the solid surface and of the ocean is so small that it is doubtful whether any exists. Certainly it cannot exceed a few parts in a hundred thousand, corresponding to an elevation of about a fifth of a kilometre.

The ability of the moon to retain a former figure, while the earth shows little corresponding capacity, is again readily explained by their origin. Their surface materials must be similar, and they have had the same time to cool. From what we know of the thermal conductivity of rocks we therefore expect that the cooling in each case will have been such that rocks at a depth of 300 km. will have cooled by about 150° C. since they solidified. This cooling would imply the acquisition of a considerable mechanical strength, which will be lacked by materials that have cooled less. Now in the case of the earth this strong shell extends only a small fraction of the way to the centre, while in the moon it extends a quarter of the way. Further, gravity on the earth is six times as strong as on the moon. Thus the force on the earth tending to destroy old inequalities of figure is six times as strong as on the moon, while the strength tending to retain them is confined to so thin a shell that it can produce a much smaller effect.

Origin of the Atmosphere

The two problems of the origin of the atmosphere and of the ocean really involve the same issue. At present various gases, including steam, are continually being sent out by volcanoes. Are we entitled to assume that all, or nearly all, of the atmosphere and the ocean has had such an origin? In the above account it has been supposed that the ocean is at any rate very old; but nothing has been assumed about the atmosphere. If the earth underwent a great expansion in its earliest stages, and in the process lost a large fraction of its material, we must expect that the loss affected chiefly the lighter constituents. Liquefaction would soon increase the density of some of these, especially those of high boiling-

points. These might help to retain such volatile constituents as they were able to absorb into solution. In this way the heavy metals and the silicates would be retained, and water, being soluble in acid siliceous magmas, might remain associated with them. Inability to form either compounds or solutions may on this hypothesis afford an explanation of the rarity of the inert gases of the atmosphere. Much water of crystallization, which must be primitive, is actually present in acid rocks. Carbon may have been retained in the form of alkaline carbonates. Carbon dioxide is among the gases given off by volcanoes, and it has been suggested that the oxygen of the atmosphere has been formed from it by the action of plants. There is, however, a difficulty about accounting for oxygen in this way. The capacity to split up carbon dioxide into its constituents, assimilating the carbon and liberating the oxygen, is limited to those plants that contain chlorophyll (that is, the green plants). The most primitive plants are not green, and convert oxygen into carbon dioxide, like animals. Thus it is difficult to see how the process could ever have started. On the other hand, we may notice that in fact all the oxygen of the earth, within 0·1 per cent, is in a state of chemical combination, and that the crust could not take up 1 per cent more than it has. This accurate balance tends to confirm the view that the oxygen was retained by chemical combination. Nitrogen, again, offers a difficulty. It forms plenty of compounds, but it does not readily enter into combination in the first place. Any nitrate or any organic compound would be broken up at the temperature of the fluid earth; perhaps some metallic nitrides could exist if by themselves, but could they do so in presence of water? There is evidence that they can, if ammonia is also present, but the question is not settled. On the whole, then, the hypothesis that most of the air and water on the earth were originally within the earth's crust and have only been liberated since solidification, is not yet ripe for acceptance; it can only be regarded as a possibility awaiting more evidence than is yet available either for or against it.

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CHAPTER III

Geology

The history of the domestic animals and cultivated plants, such, for example, as that of the production of the garden varieties of the primrose or Shirley poppy by selection of varieties met with in the wild or cultivated state, and breeding from them, prompts the inquiry whether types differing not very greatly from the primrose, such as cowslips, oxlips, and auriculas, may not have been derived from a common ancestor, possibly by the operation in nature of a corresponding method of selection. These latter groups, each of them known as a *species*, and all species whether of plants or animals, have been in the past regarded as individual entities, immutable, created in all their vast numbers separately, and divided by some mystic barrier from even those which appear to be closely related to them.

The production of garden varieties of plants, and of the different types of fowls or dogs, has involved working upon dozens of generations and has been spread over a long period of time. Any corresponding operation for the production of species, without human direction, must have involved vastly longer periods. Hence the view of immutability was inevitable at a time when it was thought that the entire history of the world was limited to a few thousand years.

Geological History

During the eighteenth century, however, the science of Geology began to take definite shape. Fossils, which had long

been known to exist in rocks, but were at first thought to be merely *lusus naturæ*, were closely compared with the corresponding relics of living forms, and in many cases were seen to be identical with them in every respect. Others, though differing from anything now living, were found not to present greater divergence than that between one living species and another. Fossils which had the appearance of sea-shells, for example, possessed similar shell structure, lines of growth, strengthening ribs, hinges and hinge-teeth, marks of attachment of the animal and its muscles to the shell and of the shell to other objects, the pearly inner layer and even sometimes fossil pearls, in rare cases the colour and lustre of the shell, and, still more rarely, the soft tissues of the animal itself recognizably preserved in mineral matter.

Fossil leaves of many different types exhibited shapes, an arrangement of petiole and blade, veins and tissues, precisely like those of plants still existing. It became impossible to resist the conclusion that these fossil forms were relics of animals or plants which also had once been alive.

The rocks in which fossils were found were exactly like sediments which had been consolidated. They could be split into thin parallel sheets (*laminæ*), and on these the fossils lay just as dead shells or drifted leaves may be seen lying on the bed of a lake or sea, until buried up in new sheets of accumulating sediment. Dozens of such layers, lying parallel to one another, each one bearing fossils, proved that these relics could not be explained by a single deluge, but must have been laid down during the quiet and orderly deposition of sediment throughout a considerable period of time.

Such a sheet of laminated sediment would be found underlain in parallel position (*conformably*) by other sheets (*strata*) of clay or shale, also of sedimentary origin and bearing fossils similarly disposed. Each of these strata gives evidence of still longer periods, and may be compared with the volumes in a library as the laminæ recall the leaves of the books. As on the pages, too, there is a story written on the laminæ if we can learn the language which the fossils speak.

The base of such a series of strata was sometimes seen to rest on other rocks, and was found to be made out of bits and pebbles broken from them, proving in two ways that one set was older than the other. When this occurred it was usually observed that the layers (laminæ and strata) of the older set were not horizontal and could not have been horizontal when the upper and newer set was formed. Presuming that strata and laminæ must have been laid down in an approximately horizontal position, that of the bed of a lake or sea, it was inferred that the older rocks had been violently tilted and disturbed before the formation of the newer ones, and this was naturally attributed to a catastrophe or cataclysm such as men were familiar with in earthquakes or volcanic disturbances. The discordance in stratification (*unconformity*) was read as evidence of such events.

As the record of rock stratification was followed downwards many examples of these discordances were met with, the rocks between each pair being stratified, conformable, and fossiliferous. Their physical history was therefore inferred to be a series of periods of quiet deposition separated by epochs of violent cataclysm, shattering the land, uplifting and depressing the sea bed, and causing ocean deluges. Further, as the fossils in the rocks below any discordance generally differed markedly from those in the rocks above, it was supposed that each debacle had also destroyed the living organisms, and that these must have been replaced by a new creation in the succeeding period of quiescence.

The first serious blow to this " cataclysmic " hypothesis was given by the " Father of English Geology ", William Smith, at the end of the eighteenth century, when he discovered that each member of a stratified series contained a definite assemblage of fossils, some of which were confined to the stratum in question and may be called " characteristic fossils ". Some of them were found to occur also in the strata below, others in the strata above, and still others in all three. Thus it was proved that long-lived and short-lived species occurred together, that change in life had occurred during the " quiet " periods

in which conformable strata were being laid down, and that this change was a gradual one, forms dropping out one by one and being replaced by others.

It also became possible to trace any given stratum, by means of its characteristic fossils, for many miles, across a whole country, even from one country or continent to another. It was then discovered that in some cases strata unconformable at one place were conformable in another, and that not only did strata filling the gap occur there, but these strata contained fossil forms of life linking the faunas of the two discordant sets of rocks. Thus many of the gaps in the succession of life were filled, and, though some remained, there was the presumption

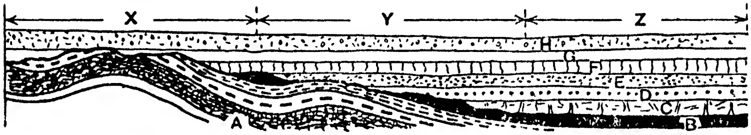

Fig. 1.—The diagram shows two groups of strata· a lower and older group marked A to B, shaded darkly, and an upper and newer group more lightly shaded and marked C to H. The strata C, D, and E are wanting in the part of the section marked X, and the relations of A and B to F, G, and H are strongly unconformable. E and D come in in the part marked Y, and are less strongly unconformable. In the part marked Z deposition has been continuous through B, C, D, &c., there is no unconformity, no time unrepresented by deposit, and the older group of rocks A to B remained beneath the sea from the time A was deposited until H was laid down.

that even these would eventually be filled as knowledge of the strata extended, giving place to evidence of steadfast succession.

As work along these lines progressed it became evident that, while the newer deposits and rocks contained abundance of animals and plants identical with forms still living, even these were generally mixed with some forms which could not be matched exactly among the life of the present. Such *extinct species* increase in number in proportion as the deposits studied are lower and older, until at last we reach rocks in which all the species are extinct and differ very markedly from existing species. Stepping back still farther, these extinct forms give place one by one to others, until, by the time we have reached the base of the known stratified rocks we have passed in review many dozens of extinct faunas or floras, each one graduating

into those above and below it: and in the lowest stratified rocks of all we meet with exceedingly few fossils and at last none at all.

The study of the fossils collected from rocks, which thus reveal the successive stages of the earth's history, yields remarkable proof of the progress of life. It is only in the newer rocks that there is any evidence of the existence of the highest group of animals, the mammals. In order of appearance the mammals are preceded by reptiles and birds, these by amphibians, and these again by fishes. Below the strata containing the earliest fossil fishes there is a vast thickness of rock yielding only the remains of invertebrate animals. Similarly among the plants, the algæ are the earliest plant fossils. They are followed by other cryptogams such as lycopods and ferns, these by gymnosperms, and these again by monocotyledonous and dicotyledonous flowering plants.

Again, taking the general character of each successive fauna or flora in turn, it is found in all its chief members to present a distinct advance on that foregoing it. So surely is this the case that it has more than once been possible, even where a newly discovered fauna consists entirely of hitherto unknown species, to indicate its position in the time scale with considerable precision.

The spectre of organic catastrophe having thus been laid, it remained to test the hypothesis of physical cataclysm. This was effected by Hutton in the eighteenth, and Lyell in the first half of the nineteenth century. Their work showed that physical processes, similar to those which can be studied in operation in different parts of the world of the present, are sufficient to account for the nature of the rocks of the past and the phenomena presented by them; that rocks of all kinds are being worn down at slow but measurable rates by rain, rivers, and the sea; that the debris is being transported and laid down layer by layer in lakes or on the sea-bed; that this sediment is being compacted into stony rock, lifted to form new land, deformed to produce the structures presented by the rocks themselves and by their aggregates in mountain systems,

sculptured and given the relief of land-surfaces, cut down or depressed beneath the sea to receive a new load of sediment; that continents, too, may have been built and mountain ranges erected without any violent catastrophe, comparable in any degree with the magnitude of the earth as a whole, but as the outcome of slow and continually renewed movements, each on a comparatively small scale; and that all this has proceeded without any disturbing effect on life such as was contemplated by the catastrophists, though it must necessarily have had its influence on the details of that life, and in providing or withholding facilities for its migration: that, in brief, the rocks which bear the record of the history of the earth are the product of an infinity of small causes operating through a vast range of time.

Theories of Darwin

The critical summation of the geological results obtained by his predecessors, enriched by those of his own travels and observations, published by Lyell as *The Principles of Geology*, came to Darwin, himself a geologist as well as a biologist, at the time that he was pondering over the problem of the origin of species.

It provided him with a sufficiency of time for the slow differentiation of animals and plants from earlier and generalized forms towards the more specialized types of later days, it peopled those ages with an ordered succession of organisms succeeding one another without any serious break, and showed that the physical and geographical changes through which they lived were brought about by a sequence of causes small in themselves but potent when operating through vast ages. On this background Darwin was able to project the results of his own observations on variation, competition, extinction, survival, inheritance, and distribution, that are summed up in his work *The Origin of Species by means of Natural Selection*, in which he developed a theory that, like Lyell's, called in the uniformitarian action of small causes.

For a statement of Darwin's theory the reader is referred

to Chapter VI, which deals with and criticizes it as applied to zoology. It is necessary, however, to point out that in view of the continual changes revealed by the geological record we have to think of organic change, not under a stable environment but in one which will tend to force on organic modification. Changes in the position and extent of land and sea, variations in the depth of sea or height of land, and the accompanying changes in climate, might render the conditions in an area no longer suitable even for a harmonized and stable species, and might compel it to migrate and face competition with forms of life from which it had been hitherto sheltered; while they would bring new factors to bear upon the survival of its offspring.

The appearance of new organisms (whether produced by a similar process of evolution or otherwise) would constitute another important factor in the environment of the species we are considering, introducing more severe competition, and requiring more perfect means of defence and attack. This changing environment, organic and inorganic, must on the whole tend to accelerate evolution, though there would doubtless be a rhythm of active and slacker periods synchronizing with the pulses of earth movement.

The facts and trains of reasoning on which Darwin relied for support to his theory of Natural Selection, viewed in the light of later knowledge and newly discovered data, have failed to convince many workers that his mechanism is adequate to produce the results attributed to it; but none of the other theories proposed in substitution for it has so far proved universally acceptable. It would, however, be incorrect to suppose that Darwin's service to science is limited by his theory. The dense array of facts marshalled by him, and the deductions he drew from them, destroyed once for all the idea of the immutability of species, and brought about the conviction that, howsoever the necessary changes had been effected, the plants and animals now living are the modified descendants of others, less highly organized and less specialized, which formerly inhabited the world.

Although the actual word was not employed by Darwin, the idea underlying his mind and work is that now generally expressed by the term *evolution*, a word now in universal use.

In the present world we are indeed looking from the outside at the surface of a tree, every leaf, twig, and branch of which is connected sooner or later with every other through a complicated system of branches springing at varying heights from one or more stems, all united at a single root. This is the idea comprehended in the word *evolution*. The process had been guessed at and even outlined in the past. Darwin and his co-worker Wallace brought us face to face with this great doctrine which now is finding its application far outside the organic world, in the mechanism of the earth itself, and beyond that again to the outer universe.

Bearing of Geology on Evolution

It is clear that Darwin recognized that the ultimate arbiter of his theory must be the record of life on the earth as revealed by geology. But it is equally clear that he looked to this study rather to give proof of general evolution than of his own particular mechanism of natural selection. His attitude to the record was that expressed by a later geologist, M. Marcellin Boule, who writes:

" The last word must lie with palæontology when that science is in a position to give a clear pronouncement. The finest anatomical works, the most subtle, the most ingenious theories on the structure of living creatures, cannot have the conclusive value of relics extracted from the rock where they were deposited and embedded in their actual chronological order."

When, however, Darwin turned to the geological record as then known, he had to admit that, though it revealed much that was in his favour, it did not give him all the support that might at first have been expected. It gave a general succession of organisms ranging from less to more perfect, from smaller to richer variety, from lower to higher grades of organization, from more generalized to more highly specialized types: it

even yielded some links between forms now distinct, but this in so few cases that he was compelled to seek an explanation of their rarity, and for the poverty of detailed evidence in other directions. This explanation he found in the imperfection of the geological record, to which he devoted a memorable chapter.

Imperfection of the Geological Record

A large proportion of organisms live under conditions that are unfavourable for the burial and preservation of their remains, such as those dwelling on land, in the air, or in the deep sea; even when living in the sea or on the sea-bed, or washed out towards it after death, the economy of nature provides for their destruction or incorporation in the bodies of living forms; only the hard coverings or other parts of those provided with them are suitable for preservation; when embedded these are often destroyed in the process of fossilization by solution in percolating waters, or else the rocks, and particularly the older ones, containing them may be so much altered chemically or mechanically as to destroy their fossil contents or render it impossible to extract and examine them; a great proportion of deposits and the fossils they may contain are destroyed during uplift and the consequent denudation by which new rocks are formed out of their debris; of those parts of each rock mass which survive, a considerable proportion may still remain below sea-level, or be buried so deeply under other sediments as to be inaccessible; even of those parts of the rocks which come to the surface of the ground and are theoretically accessible, only a fraction are exposed in cliffs, or quarries, or other excavations; the favourably exposed rocks may occur in countries not yet adequately investigated; and, lastly, most of the material quarried may not be so broken as to expose its fossil contents, and these, even if exposed, may be lost by passing in the first instance through unskilled hands, and so never reach those who could make use of the evidence afforded.

Thus the volumes containing the geological record have been defaced, and it is not to be expected that the rocks will

yield anything but a fragmentary history of the life which flourished at the time of their formation, and it is a cause of no little wonder that it had been possible to extract from them so large an amount of evidence as was in existence when Darwin's chapters were written. In spite of this imperfection, Darwin realized that the balance of evidence yielded was so much in favour of general evolution that he was content to leave the future to supply the geological evidence which was inaccessible to himself.

Recent Geological Work

Geological research since the publication of *The Origin of Species* has brought about so many advances in knowledge, that it is only possible to refer to the chief of those which have diminished the imperfection just demonstrated and have placed the doctrine of evolution on a firmer base than ever before. The area of observation has now been extended over much wider areas of the earth's surface: it has been possible to divide the record into much finer subdivisions and thus erect a more elaborate and sensitive time scale: we can now correlate strata over broad regions and indicate the approximate contemporaneity of geological events in widely separated localities: the unravelling of complicated geological structures, especially in the more ancient formations, has removed many misconceptions and erroneous impressions derived from faulty reading of the succession of strata: the closer study of processes of rock formation now in operation has enabled us to explain structures and characters in rocks hitherto inexplicable, and to derive from them evidence as to the physical, geographical, or biological conditions under which they came into existence: we have gained a clearer conception of the vast amount of time involved in that part of the earth's history comprised in the geological record, and we have seen the removal of restrictions once imposed by what have proved to be erroneous applications of physical laws: the number of known fossil organisms has been immensely increased: the definition of a species is founded upon a broader basis, its relationships to others more

clearly displayed: gaps in series, both of strata and organisms, have been filled, and considerable light has been thrown upon

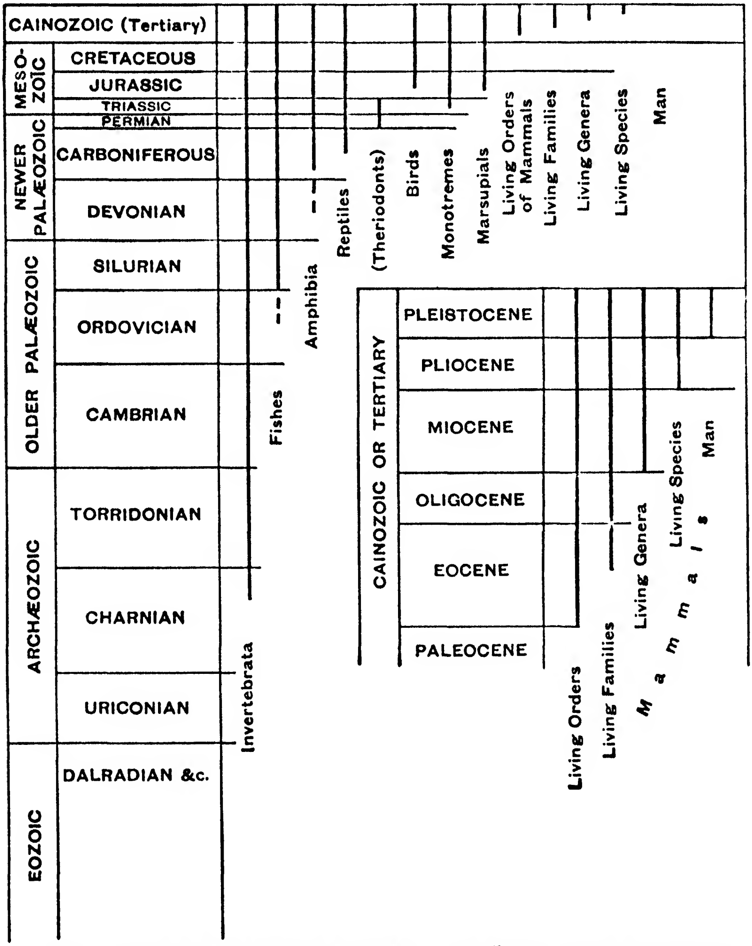

Fig. 2.—To illustrate the geological ranges of the leading groups of animals. The Geological Divisions are drawn approximately to time scale, as judged by thickness of deposits. The smaller figure illustrates mammalian evolution in the Tertiary Era.

their geographical distribution even in remote periods: whereas Cuvier in many cases had only a few bones or teeth of an

extinct form from which to restore its anatomy and habits, we, in an increasing number of instances, have larger numbers, often making up entire limbs or skulls, or sometimes complete skeletons: by more exact knowledge of the succession of minute divisions of the strata, it is possible to gauge accurately the order of succession of many trains of related organisms, and in not a few cases to ascertain their lines of descent.

While this extension of knowledge has done much to remove the imperfection on which Darwin laid such stress, it will be obvious that the causes advanced by him are still valid and that the record is yet, and in many particulars must always remain, far from perfect. Indeed, new imperfections have been revealed by more extended knowledge. For example, the discoveries of unexpectedly large faunas in the Cambrian rocks, all but the base of the fossiliferous series at present known, demands, if the doctrine of evolution is accepted, the existence of a long series of ancestral types from which the abundant Cambrian fauna was derived. Again, the study of the minute divisions of the stratified rocks and the fossils contained in them, reveals the existence of gaps in the series of deposits often not accompanied by physical discordance but implying the lapse of considerable intervals of time (*non-sequences*).

The General Progression of Life

In spite of what has just been said, there can be found in one part or other of the geological record, now in one group of organisms, now in another, successions of beings or of events in life history which are consistent with an evolution from simple to complex, accomplished during a long period of time and under the influence of a fluctuating environment.

The fossil mammals in the post-Tertiary deposits are so little removed from existing forms that identity of species is often certain. In the Pliocene rocks living species become more rare, but the extinct species can be placed in the same genera, which, however, are associated with some genera that have now become extinct. In the Miocene a few of the species

would be placed in existing genera, but the majority belong to genera now absolutely extinct. Still both these groups of genera would be placed in families which exist to-day. In the Oligocene the species, all belonging only to extinct genera, can be grouped into families, of which some still survive as families, but the rest are not recognizable as such in existing faunas. Finally, in the Eocene, while many of the fossil mammals, belonging in most cases to extinct families, can be placed in orders still surviving (such as insectivores and ungulates), many of the orders recognizable, in the older Eocene more especially, exhibit characters which would be found present in two or even more existing orders. For example, the characters of the flesh-eaters of the early Eocene are not all of them such as are found in lions, or other members of the existing order of carnivora, but include others characteristic of the lower group of pouched mammals called marsupials to which those of Australia belong. In other words the marsupial carnivores or *creodonts* exhibit peculiarities which may have been derived from marsupial ancestry, combined with others which may have given rise through successive generations to those of the genuine Carnivora. In later stages the creodonts show less of the marsupial affinities until we meet with true Carnivora at the end of the Eocene and from the Oligocene onwards. In the early Eocene Period there were also many strange, archaic types of mammals, which, after considerable evolution, died out completely.

Going farther back, mammals are very scarce in the Mesozoic rocks and all those then existing belonged to the marsupials, or to the still less highly organized group, the monotremes or egg-laying mammals, to which the "duck-billed platypus" of Australia belongs. It may be further noted that true marsupials were fairly plentiful in the Eocene but diminished in numbers down to the present time, when only opossums exist anywhere in the world outside the Australian region.

While mammals lived in the Mesozoic Era they were small in size and inconspicuous in numbers. The "lords of creation" of that Era were the reptiles, which abounded,

attained great size, were differentiated into a number of types most of which have become wholly extinct; were insectivorous, herbivorous, and carnivorous; and were able to swim in open and deep waters, to haunt the shore, to occupy the land, and even to fly in the air. Tracing them back we find that in number and types they were fewer and less important in early Mesozoic times, and they seem to have made their first appearance in the Carboniferous Period. We have no certain evidence at present that the lower group of vertebrates, the amphibians, preceded the reptiles, though it is extremely likely this may eventually be established.

The lowest group of the back-boned animals, the fishes, existed in Silurian times, and there is some evidence that they were even earlier in date, certain remains in the Ordovician having been attributed to fishes. The modern type of fishes possess a completely ossified bony skeleton in the majority of cases, though there are some few fishes in existence in which the cartilaginous skeleton is incompletely ossified. Fishes with completely ossified skeletons are not known before the Cretaceous Period, all those of earlier times being cartilaginous. While the scales of the bony fishes are thin and flexible and of little use as defensive armour, the cartilaginous fishes generally possessed strongly armoured scales, and even, in the earliest forms, strong bony plates covered with enamel. In this habit they were comparable with the majority of the higher invertebrates with which they lived, and the weight of armour and the sluggish movement enforced by it may very well have necessitated special means of defence. The modern development of speed and its defensive value was apparently not reached by the fishes until late in Mesozoic time.

Turning to invertebrate animals we find that in almost any class examined in detail there is evidence of progression. The higher orders of the crustacea to which crabs and lobsters belong have reached a more advanced stage of development in the present than ever before, and their fossil remains are found in diminishing numbers as we go back to the early Mesozoic rocks. In the Palæozoic rocks their place is taken by the king-

crabs (still living), and their relatives the eurypterids which attained gigantic size in the Silurian and Devonian Periods, and by the great swarm of trilobites which seem to have been the leading marine animals from the Cambrian to the Silurian, but rapidly died down through the succeeding Carboniferous and Permian Periods, when they became extinct. Scorpions, on the other hand, occur in the Silurian rocks, but little evidence of any leading lines of change has been extracted from their sparse remains.

The most ancient trilobites show very primitive characters. Like other crustaceans they cast their skins periodically as they grew, and the relative proportions of the parts of their bodies, and the number of limb-supporting segments of which they are composed, are seen gradually to change until the well-balanced proportions of the adult are produced and maintained. It has been shown that the earliest trilobites when adult present the characters shown in the early moults of the more highly organized forms found in the Ordovician and Silurian rocks. In other particulars the Cambrian forms stand clearly lower in the scale, and among other things they lack the means of defence given to the higher forms by their power of rolling themselves up (like a wood-louse) and exposing only their outer crust to the enemy.

The highest of the shell-fish (mollusca), the cephalopoda, have passed their maximum and appear to be now on the decline, but they exhibit the remarkable feature that different groups of them have evolved to a maximum and declined at various stages of the record. The nautiloid group though still surviving attained its maximum in the Lower Palæozoic Rocks, the ammonoids and belemnoids in the Mesozoic, and the cuttlefish group at the present day. In each case detailed evidence of evolution has been worked out to which some reference will be made later. The univalves (gastropods) seem to have been limited to few genera until Upper Palæozoic time, and to have increasingly developed through the Mesozoic up to the present. The earlier forms were vegetable feeders; carnivores came later and have been

the type in which the highest development has taken place. The bivalves (lamellibranchs) are also very poorly represented before Upper Palæozoic time, but have been increasingly abundant and varied up to the present. The places they now occupy were largely taken in earlier times by a group of animals, of lower organization than the true mollusca, known as brachiopods, which, however, also possessed bivalve shells and in their form and habits somewhat resembled lamellibranchs and carried out similar functions. These attained an early maximum in the Palæozoic era, but the shells and means for supporting the parts of the animal were heavy and clumsy. The Mesozoic types were lighter and more " scientific ", and their success gave rise to another maximum in the Mesozoic, since which time they have died down and are poorly represented in the seas of to-day.

Descending still lower in the animal kingdom, many examples might be quoted of advance in organization with lapse of time, such as the sea urchins, starfishes, crinoids (sea lilies), corals, and the hydrozoa; but there is not space to go into the details of structure necessary to make their evolution clear.

Special Adaptations

It appears to be the general opinion of biologists that animal life originated and passed its early stages of evolution in shallow water at the edge of the land, where conditions were most favourable and where such essentials as food, water, and oxygen were most easily obtainable and could be dealt with by the most primitive form of organization. Starting here the pressure of over-population would drive such forms of life as could adapt themselves to altered conditions, to migrate in four directions: to the deeper sea-bed, to the sea surface, to the mass of the sea itself, and on to the land. Migration in each of these directions would require the development of special qualities. On the deeper sea-bed there is less and less light, accompanied by a smaller amount of oxygen, special kinds of food, lower temperature, and higher pressure; life on the surface would need power of flotation and swimming, different methods

of feeding, swifter motion, and the abandonment of sedentary means of defence, in a medium with greater variation in light and temperature; life on the land requires a great number of new adaptations, not the least of them being a different method of breathing.

A comparison of the Cambrian fossils with faunas now dredged from the deep sea shows that the trilobites possessed at least one character distinctive of this mode of existence. They were either blind or possessed abnormally large eyes. In the modern seas these qualities are correlated with diminished light or the entire absence of it. It has been inferred from this, as well as from the character of the deposits, that the Cambrian fauna was living under unfavourable conditions such as are now found in the deep sea, and that adaptation to deep-sea life had already taken place. This is supported by the occurrence in the fauna of other forms, the affinities of which are with the modern planktonic organisms living on the surface of the sea, the remains of which fall towards the sea-bed after their death. It is difficult to understand from what other source deep-sea animals could have been fed, and thus it seems necessary to infer that planktonic existence must have preceded the possibility of life at the greater depths.

Among the very scanty evidence of life in pre-Cambrian rocks are burrows and trails of worms, which would indicate that not merely the surface but the mass of the mud on the sea floor had become inhabited by burrowing animals even before Cambrian times. So abundant had these become by Cambrian times, that almost every particle in vast thicknesses of rock passed again and again through the bodies of worms. Certain peculiarities in some of the trilobites of the Ordovician and later rocks indicate that some of them, as well as other organisms, also took to this mode of life.

Evidence of the first peopling of the land is difficult to obtain, as we cannot be sure that the first known examples of terrestrial animals were actually the earliest to take up this mode of life. Fossil scorpions have been found in Silurian rocks; what appear to be the remains of land plants occur

in the Ordovician. The latter became abundant and varied in the Devonian Period. Air-breathing mollusca have long been known from the Coal Measures and have recently been found even in earlier Carboniferous rocks. Various fishes are known to develop the power of breathing air. For example, the still-existing mud-fishes (*Dipnoi*), living in rivers which dry up in summer, bury themselves in mud and are able to survive the dry period by a development of the swimming bladder which for that time discharges the function of a lung. It is significant that the type to which these fishes belong was represented by numerous species as far back as the Devonian and Silurian Periods, and became very prevalent by Triassic times. It has diminished in number ever since, and now only four species exist, so far as is known.

In all probability just at first fishes may have been somewhat independent of the nature of the water in which they lived. There may even have been much less difference than there now is between the composition of marine and "fresh" water. There is abundant evidence to show that the Old Red Sandstone rocks of the Devonian Period were laid down in fresh-water lakes, and, though the rocks do not show a wide range of fossils, fish remains are exceptionally abundant, together with shells of fresh-water mussels not very different from those now living. With them are associated crustacea including the gigantic Merostomata (eurypterids) which, though an extinct group of not very well defined affinities, bear some relation to the scorpions.

The last and in some respects the most remarkable of all the conquests of animal life was that of the air. This seems to have been first attained by insects in Carboniferous times, and subsequently accomplished by reptiles, birds, mammals, and some other types. The first true flying insects were Carboniferous. Antique types, somewhat related to dragon-flies, grasshoppers, &c., have been discovered in considerable numbers and often of great size. It is a noteworthy fact that the earliest forms had not attained the power of folding their wings, a faculty which came later.

In the Trias there were numerous small dinosaurian reptiles, many of them with bird-like hind limbs, and, as may be judged by their tracks, progressing by means of these limbs alone. These three-toed tracks, when first discovered, were attributed to birds. The skeletons of a number of them were lightened by the hollowness of some of their bones. They appear to be the forerunners of the running and wading birds.

The flying reptiles called pterodactyles, however, appeared in the Jurassic Period. They possessed a highly developed fore limb with a much elongated digit suitable for supporting a flight membrane, traces of which have in some cases—as in the Solenhofen lithographic limestone—been preserved. In a few instances it is known that the membrane extended down the side of the body and may have been partially extended by means of the hind limbs. The urgent necessity of quick movement to give support to bodies in the air must have needed development in other directions. The nervous systems must have been exceedingly responsive, and the brain of a higher order than with slow-moving animals. Indeed it has been suggested, probably correctly, by Baron Nopcsa that the blood of pterodactyls was warm. There is, however, no evidence that these animals were sufficiently protected from the cold inseparable from swift movement in the air, and it seems possible that this may have been a contributing cause to their extinction at the end of the Mesozoic Period. They also came into competition with birds, of which the oldest known example is likewise found in the Solenhofen rock. This form, although possessing reptilian characters (see p. 98), was a true bird and was the first creature known to be provided with feathers. Those of the wings and tail are seen in the only two fossil examples so far discovered, but unfortunately it is not clear whether or no the rest of the body was similarly protected. The flight was probably much inferior to that of later birds, and presents some analogies with that of aeroplanes. The retention of clawed digits suggests that they were used for clinging and that ability to " perch " was not well developed.

Other types of vertebrates have taken to a partially aerial life, such as fishes and amphibia, and some of the mammals, but the true flying mammals, the bats, appeared in the Eocene Period. Their flying limbs are constructed on a different plan from that of the birds and of the flying reptiles.

The return of land mammals to aquatic life took place in the Eocene Period, when certain Cetacea occurred in the seas.

Lineages

One of the most striking arguments for evolution is that yielded by the study of the succession of closely allied species through consecutive strata. Trains of such species worked out among the mammals of the Tertiary Era indicate so slow and gradual a change in character that it is impossible to resist the conclusion that they are phylogenetically related, and present series of descendant forms becoming gradually modified during the lapse of time. Such highly specialized forms as the modern horses and camels, as shown in Chapter VI, have descended from forms more and more generalized as we trace them back through Tertiary time. In the case of the modern horse, possessed of abnormal " hands " and " feet " with but one important digit and rudimentary (and entirely functionless) vestiges of two others (the " splint bones "), we pass back in time to forms with one large and two small toes (and " fingers "), then to others with approximately equal toes, through those with three toes and a " splint bone " rudiment of a fourth, to four-toed, and ultimately to animals with the normal vertebrate limb of five digits. These changes are accompanied by modifications in the other limb bones, tending towards speed and ease of movement in the later types, by steadfast increase in size from that of a bull-dog in the earliest forms, and by important modification in the teeth, each successive change resulting in teeth more capable of dealing with grasses and grain as food.

It is only possible to mention a few other mammalian chains of descent, the camels, the elephants, the deer and other ruminants, special groups of the carnivora, such as the sabre-

toothed tigers of the Miocene and Pliocene Periods, in addition to some of the extinct groups.

Among lower forms of animal life chains of descent and lines of development have been found in the case of the reptiles and particularly the dinosaurs, pterodactyles, and crocodiles, and among the amphibia as shown by Professor Watson. The same is true of certain of the groups of fishes.

Even among the invertebrates close zonal work has revealed the same thing. The exact delimitation of species, required in order to determine with exactitude the position in a sequence of minute bands of rock, has revealed such close approximation of fossil forms in one zone to those in the succeeding and preceding zones, that it is often very difficult to draw the line between one species and another, a difficulty which increases rather than diminishes with the number of individuals studied. These remarks apply to the echinoids used in zoning the Upper Chalk, the belemnites in Lower Cretaceous rocks, the ammonites employed in part of the Cretaceous and the whole of the Jurassic and Triassic rocks, their forerunners used in the Permian and Devonian, with great force to the corals on which the zones of the Lower Carboniferous rocks are founded, and, in a marked degree, to the graptolites used for zoning the older Silurian and Ordovician rocks.

In the last case, we are dealing with a row of polypes each protected by a horny cup-like covering, connected with one another by a common portion (the cœnosarc), and forming a complete animal made of one or more branches bearing resemblance to a miniature quill. The earliest forms are highly complex and consist of a basket-like arrangement of innumerable branches. This complex branching became steadily simplified as time progressed. It is still highly complex at the outset of the Ordovician Period, but a little later the graptolites are reduced to forms in which only two primary branches are given off from the primitive cell, the "sicula". These double-branched forms, with considerable variety in the attachment, position, or furcation of the branches, characterize the rest of the Ordovician and survive into the earlier part of

the Silurian Period. Here, however, they are accompanied and finally replaced by single-branched forms which last till nearly the end of the Period, and then the entire group practically dies out.

It is, however, extremely probable that the history is more complicated than this, for in each of the various branched types it is found that the cup-like receptacle (which alone is preserved) in which the polype was contained, varies considerably in shape, position, and nature of aperture, and other characters, in the different members of a four-branched group. Similar varieties can be found to occur, with slight modifications, in two-branched and in single-branched forms successively. Thus the specific characters and lines of descent are traceable through these minute details, the grouping and number of the branches being alike at any one time in forms with several types of cup.

A similar phenomenon has been observed among other types, and in particular the ammonoids and the brachiopods. Two contemporaneous shells may appear so much alike externally that they have been considered to belong to the same genus or even to the same species. An examination of their internal structure has often revealed such differences between the two as to compel the belief that one form has descended by modification from an ancestor quite different from that of the other; but that in the process of evolution some effect of environment has produced like effects on the two forms and compelled them to approach one another in appearance. Such approximation is known as " homœomorphy ", and it exhibits some analogy with what are known as " representative species ", of different lineage, occupying corresponding environments in regions that are now, and have in the past been, widely sundered.

Changing Environment

The geological record may be expected to provide, and does in fact provide, evidence of change in physical environment, and its influence on faunas and floras. Strata of clay or lime-

stone deposited under deep or quiet waters alternate with sandstones or grits laid down between tide marks or in shallow water. The faunas and floras of such pairs of strata differ as much as animals or plants would nowadays if living under such diverse conditions. If the upper of two sand-beds is separated from the lower and earlier one by only a small thickness of clay or limestone, the sand fauna may come back again and the fossils of the second will present very little difference from those of the first. If, however, the clay series is thicker and has occupied considerable time for its deposition, the second sand fauna or flora will differ in part or altogether from the first. There has been sufficient time for life change to occur at the localities to which strand lines have shifted during the interval.

Changes in relative level of sea and land have often occurred on a great scale. An example occurs in the extension of the Chalk over vast areas which had been land in earlier times, while the converse change is shown in the great uplift at the beginning of the Tertiary Period when even the floor of the Chalk sea was converted into continental land. These great movements are found to be accompanied by far-reaching organic changes. Subsidence in land regions, diminishing their extent, will crowd the organisms into a smaller space, and at the same time diminish the area of their food supply. This will clearly give rise to much sharper competition both for space and food, which must necessarily result in the elimination of the forms less favoured than others with the means for attack and defence, of those that have become specialized as to their food requirements, and of those requiring a wide range to follow their food supply in the changing seasons. The survivors will be the more strong or active, those most cunning in concealment or in the capturing of food, the swiftest, and those endowed with special endurance; in a word those most capable of adapting themselves to the new environment. On the Darwinian hypothesis this should lead to the production of new species among the survivors, not perhaps in very large numbers, but diverging somewhat rapidly and markedly from their parent forms.

In the sea, on the other hand, the newly submerged land edges would present unoccupied areas suitable for shore-living and shallow-water forms, and new opportunities and advantages would be open for them, leading, on the same hypothesis, to the production of new species in some abundance. The inhabitants of each depth-zone of the seas would similarly migrate landwards and would also enjoy the advantage of fresh ground, but with some new competition as they advanced. The wider extensions of the oceans would similarly affect the organisms living on the surface and in the mass of the waters.

The reverse process, the elevation of land or the retreat of the sea, would be all to the advantage of terrestrial forms, while contracting the area and increasing the competition of marine life.

Other and more local effects will follow from upward and downward movement. Shallow areas between continents or islands may become converted into causeways or bridges which, while giving highways of migration to land-animals, will cut off communication between parts of the sea previously united. Great disturbances in the balance of life are certain to occur as a consequence of migration and counter-migration along the new bridges; and acute struggle, especially between those forms closely adapted to particular modes of life in the one area and those similarly adapted in the area now connected with it, though these may be of different affinities, origin, and biological history. For example, the present continent of Africa has been produced by the union of two separate land-masses, divided in Tertiary times by seas. On these two land-areas independent evolution produced distinct groups of organisms, especially among the plants and mammals. These, by the disappearance of the intervening sea, have now been brought into contact and are both intermingling and competing with each other. Former connections between the Atlantic and Pacific have been so recently severed by uplift that there is not as great a difference between the faunas of the two sides of the Isthmus of Panama as might have been expected.

On the other hand, subsidence and the breaking of con-

necting links has isolated one area from another, perhaps a large and diversified region from one smaller and more monotonous, and thus has left each to pursue its own evolution sheltered from competition with the other. Examples of this will be discussed later, but a reference may here be made to the geological evidence that in late Tertiary times the Mediterranean was broken into three separate basins by ridges that are now sunk again beneath the sea. This former connection accounts for peculiar mammalian remains such as those of an extinct pigmy elephant found in North Africa, Greece, Cyprus, and elsewhere; and it also explains the present relation of the North African fauna and flora to the European in contradistinction to its difference from that of the rest of the continent.

While continental uplift has been responsible for the elevation of plateaux, more concentrated forces have acted upon limited ranges of land and ridged the rocks into mountain chains. These have naturally acted as barriers to intermingling, and, by altering environments, must have had a considerable influence upon competition and evolution. Mountain ranges in many cases at the present time act as barriers to wide-spreading species, partly on account of the physical obstacles they present and partly by the cold and snow of their higher levels; and there is evidence in some cases that this has caused independent evolution on the two flanks. To mountain-living forms of plants and animals, however, the ranges will give new highways for migration.

Land elevation has, without doubt, made its contribution to bringing about widespread climatal changes such as that of the Pleistocene Glacial Epoch, and possibly of earlier ones through which parts of the earth have passed. The succession of fossil floras and faunas found in the glacial deposits and those associated with them swept to and fro over the land in response to the varying climate of the Epoch, and this has clearly influenced the evolution of these forms of life. Indeed, the on-coming and off-going of the Glacial Epoch has been one of the most powerful and cogent factors known in migration and the evolutionary changes consequent upon it, and one the

effects of which may be easily studied in the distribution of modern faunas and floras. Assemblages of "Alpine" or "Arctic" plants are still to be found on mountain heights far from glaciated regions, relics left stranded on the retreat of the cold and forced to find the temperature conditions they require by following the retreat of the ice margin upwards, and there still struggling against extinction as the amelioration of the climate allows their competitors to advance steadily against them.

Again, mountain elevation has had special influences on rainfall, and by the shelter thus afforded has given rise to desert tracts on the lee side of the ranges. Within the deserts suitable life assemblages have arisen by special adaptation from those available and at hand during each of the great mountain-forming periods through which the earth has passed. Mountain building has further given rise to modification in drainage systems and to consequences in deposition, drainage, vegetation, &c., which cannot have been without influence on the organisms of the region.

Some Biological Peculiarities

In our ordinary experience we often meet, in common objects, with needless peculiarities, the existence of which can only be explained by studying the past history of the objects that exhibit them. The shape and build of the windows and doors of an English railway compartment (particularly at the end of the last century), and its transverse arrangement, are the descendants of characteristics of the horse-carriage, and they recall that in the earliest trains passengers travelled in their own carriages placed on trucks. Crossings of stone setts were a necessity and a blessing when town streets were macadamized and muddy; they are often renewed at the present day though in streets which are waterproof and clean, and in some places the position of former crossings is still conscientiously marked out by two rows of setts running across the street although the actual crossing between the rows is now made of the same material as the rest of the road. Many details

of the modern locomotive, some now functionless and even disadvantageous, derive from Stephenson's " Rocket "; entrance-hall lamps are still built on the lines of a cresset; and standard street lamps, and even lamps newly designed for motor-cars, though lighted electrically, provide means for the entrance of air without draught and for the exit of smoke.

Similarly among animals peculiarities in structure or organization, now useless, still persist as so-called rudimentary organs, or vestiges, but are of interest as survivals of some organ or condition which was of use to the ancestor of the form in question.

Brief reference has already been made to one striking example in the two small splint bones at the side of the middle digit of the horse. That these are really all that is left of two lateral digits is proved by the occurrence of an occasional throw-back in the birth of a colt in which the splint bones are larger and support two small hoofs which are functionless and do not reach the ground. Geology confirms this conclusion by the anatomy of the fossil remains of the Tertiary ancestors of the horse, in the later of which the three hoofs are like those of a " throw-back ", while farther back in time we have horses with three well developed hoofs.

Stages in growth are often difficult to explain until light can be obtained from early history or stages in evolution. For example, young deer have no antlers till the end of their first year. The growth of the second year is simple and without any tine. After the first shedding the second growth has a brow tine only. Later on successive tines are added year by year until antlers of much complexity are produced. The earliest fossil deer from the Eocene rocks are hornless; they are succeeded by forms with an unbranched antler, these again by forms with a brow tine only, and later fossil antlers show more and more complexity until a maximum appears to be reached in the Pliocene and Pleistocene Periods. Thus a modern deer in a few years passes individually through modifications which its ancestors have taken four geological Periods to complete.

Sometimes, however, modifications of this kind are passed through in the very young or even embryonic stages, modifications which are not only useless but may be a positive encumbrance, and at the best must use up energy and material which could be better employed if, so to speak, the modern forms were designed *de novo*. The embryos of certain forms of the Cetacea develop teeth of mammalian type which are never cut, and are actually absorbed and disappear before the birth of the animal. The successive early stages in the growth of the higher trilobites and their comparison with the highest development attained by the adult of the earliest known trilobites have already been referred to.

The most remarkable case, however, is the apparently symmetrical tails of the modern bony fishes. The embryology of these fishes shows clearly that the " symmetry " is a secondary character following upon and derived from an original asymmetry. In these embryos the backbone is prolonged and is fringed with one fin, while a second fin is developed below it. As the embryo grows the prolongation of the backbone turns up and shrivels and with it its fringing fin, while the lower fin, growing upwards and round the end of the body, eventually develops into the two-lobed fin which constitutes the " homocercal " or " symmetrical " tail of most modern fishes. The termination of the vertebræ, however, throughout life preserves in the detail of its shape an unobliterated short-hand note of its history.

The only rational explanation of such a process is that the individual is passing through a series of changes which the whole group of fishes has passed through in its former history and evolution. This has been expressed by the saying that " an animal in its individual development climbs up its own genealogical tree ", or " ontogeny is phylogeny in a shortened form ". And this is precisely the case. The number of fishes with heterocercal tails steadily increases as we trace the fossil forms backwards, until we find that all the earlier fishes, from the Silurian Period to the Trias, are heterocercal.

The phenomenon of impoverishment, shown in faunas

which although abundant in individuals are limited to a comparatively small number of species, suggests derivation from richer faunas isolated for considerable periods in areas in which unfavourable conditions have supervened. Shell-fish related to those of the open sea are abundant individually in the freshening waters of the Baltic, but they belong to a few hardy species, and of these some, such as the oyster, differ from open-sea forms in the shape and thickness of their shells. This phenomenon finds its parallel and explanation in the geological record. As an instance the rich and varied fauna of the Carboniferous is followed in Britain by the meagre and impoverished fauna of the Permian rocks. The Magnesian Limestone which contains the Permian fossils was precipitated in enclosed salt lakes in a dry climate. The forms present are so obviously related to those of Carboniferous times that they must be regarded as the modified descendants of such of the Carboniferous fauna as could live under these conditions. Though few in species the fauna is rich in individuals for the reason that they flourished in the absence of former rivals that had been killed off by adverse conditions. But as the waters grew more briny, circumstances became too trying for one species after another and they were successively eliminated. The fauna thus became more and more impoverished and at last died out altogether. The evolution which it underwent indicates shelter from outside competition brought about partly by the immediate environment (the nature of the water) and partly by geographical isolation. Meanwhile, in other regions where marine conditions persisted from the Carboniferous throughout the Permian Period, we find that organisms of Carboniferous type were one by one displaced by newer forms, and a fauna originated which is full of transitional forms passing towards those which characterized the rocks of the succeeding Mesozoic Era.

Geographical Distribution

When the geographical distribution of animals and plants over the world is studied, many peculiarities are found which

can be accounted for by conditions of soil and surface, of food and climate, of association, and of facilities or barriers to spreading and migration. But there are other facts that do not admit of explanation by features or phenomena now existing. For example, almost the whole of the land of the northern hemisphere constitutes one great distributional province (the *Palæarctic Province*), which not only includes the connected land mass of Eurasia but North Africa and North America, which are severed from the rest by seas. It has already been stated that, in times past, bridges existed across the Mediterranean. A bridge also existed in Tertiary times across the North Atlantic by which facilities for intermigration between the old and new world were provided.

Far greater difficulties exist in relation to such distributional provinces as South America and South Africa, each with land connections with the "Palæarctic" Province, and yet very different in their organisms; and to Australia which is without such connection.

When Australia was first discovered, all its mammals, with one exception, and those of certain neighbouring islands, belonged to two orders, either the marsupials which include the kangaroo, wombat, and opossum, or to the lower order of monotremes to which the duck-billed platypus and spiny ant-eater belong. These are now giving way before imported placental mammals, more highly organized and better equipped for the struggle for existence. It would appear that Australia must have been completely sheltered as it now is by the sea from the immigration and competition of these higher forms.

Geological evidence is in favour of this. The isolation appears to have been of very long standing. At present marsupials are all but absent from the rest of the world. As we go back in the Tertiary Era the numbers of their species increase, and in the Eocene Period they make up a considerable proportion of the mammalian fauna. In this Period too there are other orders such as the creodonts which exhibit such strong marsupial affinities as to indicate that they were derived from marsupial stock.

Going back to the Mesozoic Period we know of no fossil mammals except marsupials and monotremes. It therefore seems reasonable to infer that it was in Mesozoic times that Australia was connected by land bridges with the rest of the world so that forms originating on either side of the bridge could intermigrate. If the connection were broken at the end of Mesozoic time evolution might well take different lines in Australia—a continent of low relief, with not a very great range of climate, with a large proportion of desert area in the interior, and with a comparatively simple river system; differing in these and other respects from the nearest continental area, and especially from those parts in closest proximity. Support to this conclusion is given by the fact that all the Tertiary mammals hitherto discovered in Australia are also marsupial, differing from existing forms, but such as might be ancestral to many of the species now living in Australia. Further support is received from the fact that the flora of Australia is peculiar and also has Mesozoic or early Tertiary affinities, and that certain shells belonging to the genus *Trigonia*, and terebratulids like those in Mesozoic rocks, are now found in Australian seas, but are absent or rare elsewhere.

The peculiar character of the fauna and flora of South America is in part accounted for by the geological fact that that continent was disunited from North America from Eocene to the end of Miocene time.

A remarkable distributional fact is the occurrence of the few surviving species of the lung-fishes belonging to the dipnoan group. These now live exclusively in rivers in the southern hemisphere; one, the barramunda (*Ceratodus*), in Australia, and two (*Lepidosiren*) in the rivers of South America and South Africa. Such a distribution of forms, limited in power of migration by the fact that they inhabit fresh water exclusively, is inexplicable unless the living forms are the survivors of a *Ceratodus* fauna once widely spread and capable of reaching these areas now isolated. Fossil evidence shows that this group of fishes was in existence in the Silurian Period, flourished in great abundance throughout the Devonian, Carboniferous,

Permian, and Triassic Periods (when it was particularly abundant), and has lived on, though in steadily diminishing numbers, ever since. It now survives in those places only where its remarkable habits allow it to endure conditions of flood and drought which are fatal to other, though more highly organized, fishes.

"Retreat" and Swarming

There are certain phenomena that would seem to be inevitable on any hypothesis of evolution which presupposes that there is steadfastly advancing adaptation to environment whether stable or changing. A fauna or flora will tend to increase up to the limits of its means of subsistence; its members will each extend the area occupied by it until impassable barriers are reached. It will "fill" that area so that new forms originating inside or immigrating from outside will have to meet a most strenuous resistance, and will find the utmost difficulty in carving out a place for themselves. Some may be fortunate in gaining entrance by reaching places where evolution has been slow; or where, owing to isolation, the higher forms evolved have become degenerate in means of defence owing to the absence of serious competition. Here an easy victory and early establishment may take place accompanied by the sudden extinction of overgrown and defenceless forms like the giant birds of New Zealand, Madagascar, Rodriguez, and Mauritius.

But usually conditions will be otherwise, and immigrant or newly developed forms will find the whole population in arms against them, and must live by concealment and subterfuge perhaps for ages until they have acquired properties which may enable them to establish themselves in a leading position against their competitors. This period of "retreat" has been recognized in the incoming of many new forms of life. Remains of the earliest fishes in the Silurian rocks (still more in the Ordovician) are extremely scarce; the same occurs with the reptiles in the Carboniferous, and the mammals in the Mesozoic rocks. It would hardly be fair to quote the earliest

birds, considering the small chance for the preservation of bird remains. The same " tentativeness " is also observed among zone fossils, such as graptolites and echinoids, which are open to special note as they are observed and collected in quantity in the process of working out the sequence of rocks or in establishing correlations.

This tentative stage is, however, in most cases followed by a period of very extensive development when the new type has made good and is making its dominance felt. This might be spoken of as the " boom " stage and is well marked by the tremendous domination of fishes in the Devonian Period, of reptiles in the Mesozoic Era, and of mammals in the Tertiary. In a humbler way we have the dominance of the graptolites when they had discovered a method of occupying the surface of the sea by attachment to floating weed, and the boom of ammonoids, belemnoids, echinoids, the *Rudistes* group of mollusca, and the corals, each in their own time. In the vegetable kingdom we may see the phenomena of intensive development in the successive dominance of the vascular cryptogams of the Carboniferous, the cycads of the Mesozoic, and the phanerogams in the Tertiary rocks. In each case they are either the highest product of the time or they enjoy a special advantage through the perfect harmony with their environment that they have attained.

" Blind Leads "

Not infrequently the geologist is confronted with what, viewed from the present standpoint, appears to be the sudden extinction of whole groups. The dominance of cryptogams comes to an almost sudden close in the Palæozoic Era, as does that of the reptiles at the end of the Mesozoic. At this latter stage too the great numbers of belemnoids and ammonoids come to an absolute end. Again, compared with the time occupied by the rise and climax of the graptolites, their decline is rapid as measured by the deposit of a few hundred feet of rock. It is difficult to resist the conclusion that there was something inherently wrong in the organization of these forms; that

their evolution in its early stages was along lines which, under existing environment and its sequel, were quite satisfactory, but which produced forms that became too highly specialized to adapt themselves further and rapidly when serious changes in environment began to occur. They had taken the wrong turn where the road forked, and, though the road was good and the prospect entrancing, every step along it took them farther and farther away from the path to the goal originally aimed at.

The graptolites, having discovered and peopled the sea surface and thus getting the advantages of light, warmth, and food, and avoiding any serious enemies—for the trilobites were at best a feeble folk—were suddenly confronted with the incoming of the fishes. We can almost see them putting on a defensive armour of fibres and spines in a despairing effort to make things as unpleasant as possible for their new enemies. These devices did not succeed and the whole race of them went under.

The development of armour has throughout geological history been a constant temptation and one highly dangerous to those that have taken this " primrose path ". A few examples may be given: the heavily plated fishes of the Devonian Period; the development of granules, scales, and spines by the dinosaurs, followed by groups more and more heavily plated, encased, and spined; the occurrence of horned, armoured, and plated forms in some of the Tertiary mammals. In each case the method proved a simple and easy defence against congeners with carnivorous propensities and the qualities which go with them. But in each case it involved great strain upon the organism. The weight of the armour compelled a more sedentary life and sluggish habit, and the food-hunting range became restricted; there was a heavy drain upon food and vital energies to supply the armouring material, and to make good repair, and the additions, or in many cases renewals, required to accommodate the growing animal; there would be an almost inevitable tendency towards large size and cumbrous form. In the majority of cases where this method of passive resistance has been resorted to, the forms adopting it have gone under in

competition with those which have developed weapons of attack, teeth and claws, necessarily accompanied by activity, speed of movement, and swiftness of attack. With this has come also the "short-circuiting" of the process of metabolism, giving the carnivores an undeniable advantage over those living on vegetable food—almost the only kind accessible to heavily armoured forms.

The geological record furnishes many other examples of such "blind leads", nature's unsuccessful experiments. In most cases we do not yet hold the key to the inherent weakness which caused their downfall. The entire class of reptiles is probably one, the marsupials another, and many mammalian orders, such as the Condylarthra, Amblypoda, Ancylopoda, Tillodontia, and Creodonta, which have gone out without leaving direct descendants and without, in their later and more specialized stages, contributing anything of particular importance to the chain of creation. They were branches of the tree of life which have died and withered and become lost, except that they left knots in the wood of stem or branches.

Study of the ammonites indicates the development of complexity in the structure of their shells, especially in the shape of the supporting septa and the line of contact of these with the outer shell. While the septa of the nautiloids which preceded them were gently curved or spherical, those of the ammonoids become more and more highly "crumpled" as time passed. The same amount of support can be obtained from a buckled, dished, or corrugated partition as with a greater amount of material disposed in a plate of simpler section. In addition to the economy of material thus secured, the buttressing afforded to large areas of the outer shell by the crumpled edges of the septa, and the arch-principle adopted throughout, allowed that also to be constructed on a lighter plan. It may well be that the facilities this offered may have conduced to a too parsimonious use of material which brought about the downfall of the group; while the nautiloids, never too economical and never very abundant, have outlived them and persist from the Cambrian seas to those of the present day. This

subject suggests a tempting analogy with the evolution of architectural style from the Norman to Flamboyant Gothic.

Even when accompanied by armouring, and still more without it, the attainment of excessive size, or of very high specialization, is a dangerous line of development. It is only possible of acquirement under easy circumstances of food and safe environment, and it must remain sensitively affected by these two factors, always prone to change. Animals of great size are especially attractive to enemies that by working together can make up by numbers what they lack in individual strength. It is significant that in many cases the extinction of fossil types has been preceded by their excessive growth.

Correlated Evolution

Certain stages in the evolution of plants have been of especial significance to mankind. The results of the dominance of cryptogamous vegetation in the Carboniferous Period and the preservation of it in the form of coal, are incalculable. Another stage almost as striking is that of the incoming and evolution of the grasses.

Some types or other of herbaceous plants, shrubs, and trees have existed at least from Silurian times, but it was only in later Eocene times that the grasses made their appearance. After the usual period of " retreat ", they began to make their presence seriously felt in the Oligocene Period and have since become the dominant plants of the world. Their habits of growth enable them to spread rapidly, and monopolize the ground they take up, by the formation of turf. They have colonized the valleys and plateaux, the prairies and mountain slopes, and indeed it is only ice and deserts which have conquered them, though the outcome of their struggle with forests is still undecided. What is of chief interest at the moment, however, is the effect of the new grass environment on the evolution of animal life. New forms of grass-feeding insects and other lowly forms made their appearance, providing food for birds and stimulating their evolution. Mammals took to the grass-food, their teeth and digestive organs undergoing changes in

order to deal with it more effectively, and hosts of new types of herbivorous mammals made their appearance and rapidly increased in numbers. But as the grass ripened and died down it became necessary for these animals to follow their food into areas not yet past their harvest-time, and again to migrate back from the snow and other consequences of the winter cold. This necessitated modification in the direction of speed and endurance, and the scrapping of all defensive measures except such as were also of service in migration and did not interfere with speed and freedom of movement.

The evolution of vast numbers of herbivorous animals comparatively defenceless, brought about the development in corresponding numbers and variety of flesh-feeding and blood-drinking animals, and we find abundant fossil evidence of this development in numbers, size, strength, and variety. New methods of defence in addition to hoofs, horns, and speed were enforced upon the herbivores, who took refuge in " mass-action ", formed into herds under leaders, and developed means of combined defence. Herd formation and leadership proved also an advantage at times of migration, but it resulted in the adoption of the same tactics by certain of the carnivores.

It may be noted, though this is not part of our present purpose, that in this fashion not only did grasses (including bamboos, corn, rice, millet, and sugar-cane) directly introduce new food supplies into the world on a vast scale, furnishing subsistence directly to man, but it indirectly provided him with herbivorous quadrupeds which also served for food. Further, man has made use of the herd instinct of these animals, and even of some of the carnivores, in order to domesticate them and make them still more serviceable to his own ends.

Brain Evolution

One of the most remarkable results obtained from the study of the better preserved fossils of vertebrates discovered in recent years is the evidence yielded by them as to the evolution of brain. That is best expressed by comparing the weight of

brain—the directing mechanism—with that of the entire animal directed by it.

Brontosaurus, a great Mesozoic reptile, weighing about thirty-seven tons, had a brain of not more than two pounds, less than one ounce per ton. Triceratops, another reptile of later date, and weighing ten tons, had one of about the same weight as the last, about three ounces per ton. Dinoceras, an early Tertiary mammal, weighing two tons, had about the proportion of half a pound of brain per ton. The ratio with a gorilla would work out at about ten pounds to the ton, with a dog, twenty pounds, and with man, 3·3 pounds to twelve stones, about half a hundredweight to the ton. From this series of figures it will be clear that the mammals stand out from the reptiles, and that there is progressive increase in brain capacity—so far as it can be measured by weight—from the earlier to the later forms, the process accelerating in its later stages until it culminates in man. In this increase among mammals, and in the capacity for it possessed by them, we may possibly trace the reason for the failure of the reptiles to which an earlier reference has been made. They were advancing along a " blind lead ", the development of strength and activity of body and limb before adequate directing mechanism had been evolved, and with an organization in which such evolution was impracticable. In the dominant and most advanced group of the Mesozoic reptiles, the dinosaurs, it has been found that there was developed a second great nerve centre, sometimes more than ten times the weight of the brain, in the lower part of the vertebral column, by which the limbs were in part controlled. Such nerve centres, but on a much smaller scale, exist in the mammals, but the tendency in the evolution of these animals has been to concentrate the command in a single great nerve centre, the brain.

Difficulties

There are certain outstanding difficulties in the record of the actual succession of life which unquestionably demand explanation if the doctrine of organic evolution is to be accepted.

Some of them were dealt with by Darwin; of others we can offer explanations that were inaccessible to him.

Side by side with continuous advance and improvement we have the living on of certain, usually lowly, forms, without any considerable apparent change. Species of *Lingula*, not markedly different from those living in the seas of the present, are preserved in the Cambrian rocks, and are followed by abundant forms in the Silurian and by less abundant ones in later rocks. The genus *Nautilus* of the present seas comes up to us from the Cambrian with little change. Brachiopods, not very different from those swarming in the Jurassic and Cretaceous seas, occur, though sparsely, in the oceans to-day. Although some types of foraminifera have been vastly developed in past periods and afterwards died out, there are other genera which have persisted throughout nearly the whole geological record and are abundant at the present day.

Such cases are not easy to account for. It may be that they have early attained complete harmony with their environment, which has not been disturbed by the comparatively small changes which have occurred therein. Conditions have probably not seriously changed in the deep sea from Cambrian time onwards. Other forms may have hit upon advantageous structural methods which have given them stability in competition with congeners that have tried experiments which bear the seeds of their own undoing.

A second difficulty which confronts the geologist is the lack of evidence as to the origin of the great phyla into which the animal and plant kingdoms are divided. Connecting links between, for example, modern amphibians and modern reptiles, or reptiles and birds, with the characters that they now possess, are, as Darwin pointed out, not to be expected. We are looking at the ends of branches the connection of which with one another is far back in history and may only occur through the main trunk. What might be expected is the occurrence of generalized forms from which two or more phyla now separated may have branched out. That with all the chances against the preservation of any particular form, such critical types should be pre-

served or found would, as Darwin showed, be very remarkable. Such cases as exist are therefore correspondingly precious, and the evidence yielded by them of unusual interest and significance.

It appears to be admitted that the origin of the mammalia is to be looked for in the theriodonts, a fossil group of Triassic reptiles, especially well preserved in South Africa, but with representatives in the British rocks. It is significant that fossil remains from the Trias which have been generally supposed to be the earliest mammals known, have by some palæontologists been considered to be theriodonts.

Archæopteryx, the earliest known bird, the remains of which have been found admirably preserved in the Jurassic lithographic stone of Solenhofen, and are known from only two specimens, exhibits numerous reptilian characters and is clearly a link between these two phyla. It is bird-like in the possession of wing and tail feathers, power of flight, and the adaptation of the fore limb to support the wing feathers. It has strong reptilian affinities in the skull and brain, in the possession of a toothed jaw of reptilian type, in the fore limb with three digits armed with claws (probably used for prehensile purposes), and in its reptilian tail composed of a chain of vertebræ each one supporting a pair of tail plumes, in place of the terminal "plough-share bone" of a modern bird from which springs the fan of tail feathers. The only two species of birds found fossil in the succeeding Cretaceous rocks have become much more birdlike. The fore limb, brain, and tail are like those of modern birds, but the reptilian character of teeth in the jaw still persisted.

The older Tertiary creodonts, as has already been pointed out, are linking forms between two separate classes of the mammals, the marsupials and the carnivores, and some of them have affinities with other mammalian orders; and in the Tertiary rocks generally, numerous other forms linking separate mammalian orders, and separate sub-orders within the orders, have been discovered and described.

The third difficulty to which allusion has been made, is the

apparently sudden appearance of eight of the nine great phyla of the animal kingdom in the Cambrian Period; and of six of these in the earliest Cambrian strata. It is true that each phylum is represented by lowly forms, but the trilobites are still trilobites and as such are high up in the invertebrate scale. If this is really the beginning of life, evolution in these early stages is at once disproved. But a closer survey of the whole of the evidence suggests an alternative explanation, that the Cambrian fauna is itself descended from a long range of earlier ancestry. That of the Lower Cambrian rocks is an impoverished one, such as is usually proved to be related by descent to a richer foregoing one. It is distinctly specialized, and shows the characters usually found in a deep-sea assemblage, such as might have been expected to have separated out from a richer fauna and to have adventured out into a new environment. Further, the pre-Cambrian rocks are not absolutely devoid of fossils, but, though singularly refractory, have yielded traces of worms at several horizons and, in Western America, what are considered to be imprints of soft-bodied animals with horny (chitinous) tests.

The paucity of fossils in these Formations, which probably equal in thickness all that succeed the Cambrian, has given rise to several hypotheses. It has been suggested that the rocks may have been formed under terrestrial (and volcanic) conditions unfavourable for preserving fossils, but though this explanation may apply to certain members it does not apply to all.

Professor Daly explains the exceeding rarity of pre-Cambrian fossils in another and most ingenious way. Noting that such fossils as exist are of animals which are soft bodied or only protected by chitinous covering, that practically all the Lower and Middle Cambrian fossils possess chitinous tests only slightly strengthened by lime salts, and that shells made in the later fashion out of carbonate of lime are absent, he hazards the conjecture that the pre-Cambrian forms were not provided with endurable calcareous tests because the necessary supply of sulphate or carbonate of lime was not available for them.

Scavenging animals, which evolved in later times in in-

creasing numbers, and at the present day secure the prevention of putrefaction on the sea-bed by using up the dead bodies and even the excreta of other forms and reconverting them into living matter, were very few in Cambrian, and absent in pre-Cambrian times. Putrefaction of dead forms which have lived on the bottom or showered down from above, would give off carbonate of ammonia that would precipitate the limited supply of lime salts brought to the sea from the disintegration of the calcareous silicates of igneous rocks, depriving organisms of the opportunity of using it; a condition of things now brought about by other agencies on the floor of the Black Sea.

The majority of the pre-Cambrian organisms were thus unable to leave in the deposits of those ages fossil relics of their existence in an enduring form. It was only on the uplift at the end of pre-Cambrian time, and the denudation of the extensive supplies of carbonate of lime provided by precipitation in pre-Cambrian seas, that a sufficiency of material for strengthening the Cambrian chitinous shells was provided, while the development and extension of the scavenging system gradually prevented the waste of lime by precipitation, so that enough of it was left in solution in the waters to provide material for the rapid evolution of lime-using forms from Ordovician times onward.

So much has been done towards solving these geological difficulties that we may now await the accumulation of fresh evidence, confident that the doctrine of organic evolution is firmly based on the general consensus of proof afforded by the geological record.

Evolution of the Earth Itself

When minor events are eliminated, the geological history of such a region as north-western Europe reveals a rhythmic succession of marine invasions separated by periods of continental expansion. Although these are not world-wide, they are known to have so great a geographical extent that they may be regarded as typical events in the world's history. In Britain we can count three marine incursions of prime importance;

the first lasting from the Cambrian to the end of the Silurian Period; the second occupying early Carboniferous time; and the third extending from the Jurassic Period through the Cretaceous until the Oligocene. These are separated by three eras of land extension and mountain-building; the first, known as the *Caledonian*, occupying the Devonian Period; the second, the *Armorican* or *Hercynian*, the later Carboniferous, Permian, and Triassic Periods; and the third, the *Alpine*, the Oligocene, Miocene, and Pliocene Periods. There was also evidence of one great period of land extension in Britain, the *Charnian*, before Cambrian times, and evidence from Canada, Finland, and elsewhere that in these Archæan times there were at least two periods of mountain-building, and a sufficient lapse of time for the successive destruction of the ranges produced by each of them, before the Cambrian seas began to invade their margins and to encroach on their territory.

Each of the cycles of mountain-building gave rise to the folding, fracturing, and metamorphism of rocks, to intense disturbance and inversion of their succession, to the outburst of volcanoes and intrusion of molten rock from below among the stratified rocks, and to the development of systems of lakes and rivers, of plateau, range, valley, and plain, and the production of areas of desert, forests, swamp, shrub, or pampas.

The history of these cycles is recorded by destruction rather than by deposit of strata, except at the margins of the uplifted areas. But lacustrine sediments, screes and gravel, swamp, forest, and delta deposits, such as coals and coal-measures, old soils, deposits in caves, or from glaciers or ice sheets, may be at times almost miraculously preserved.

Marine transgressions are associated with tranquillity in the history of the world, with the quiet deposit of material denuded from the land, and with either mechanically borne sediments, coarse in texture at the base and margin, fine grained, and growing but slowly, farther from shore, or chemically dissolved lime or silica taken up by organisms and deposited as oozes, limestones, or cherts, in the quieter, deeper, or more central areas of the ocean basins. The strata are conformable, their

sequence often complete, life forms well preserved, and the evidence of organic evolution convincing.

The sequence of these great pulses is broken by a vast number of minor changes of land and sea into the details of which it is impossible to enter.

Whether marine transgressions are due to movement of the sea or of the land is a matter still in dispute. One thing is clear, that the periods of regression are often accompanied by intense lateral movement of the earth's crust, crushing into narrower spaces rocks which have been previously spread over wider regions. It has been suggested that as the greater sequences of sediments have been laid down during the gradual deepening of long, relatively narrow, marine troughs, the process of deepening these "*geosynclinals*" draws the water away from the widespread shallow seas on the continental margins: and that when the geosynclinals fill with sediment, or close up by earth-movement, the excess of water passes on to the lower land to form "epi-continental" seas.

In any case it is impossible to avoid the conclusion that the earth crust is in a state of constant activity, finding rhythmic expression in cyclical changes in its outer contour, and in the growth of rock in which the changes are recorded. Authorities are not in agreement as to the cause of this activity. It has been generally supposed that shrinkage due to the gradual cooling of the earth has been the cause, but, apart from the fact that crust movements have been far more extensive than could be explained by plain shrinkage, the physical laws of radiation insist that at the present rate of heat escape from the earth the world of twenty million years or so ago would have been too hot for life to exist on it. This period is too short for the physical events of the geological record, and for the evolution of life from Cambrian time onwards. Further, there is no proof of excessive heat at the surface so far back as the history of fossiliferous strata extends, while there is evidence of widespread glaciation in Permian and almost certainly in pre-Cambrian times.[1]

[1] Compare Chapter II, p. 40.

Professor Joly has pointed out that, whether or no general cooling of the earth is in progress, the surface effects would be best explained as the result of the output of heat from radio-active material situated in the outer part of the earth's interior. He considers that this would have the effect of liquefying periodically a layer of basic " magma " which underlies the oceans and supports the continents and mountain chains. During the process of heat accumulation, and the expansion and liquefaction of this layer, the outer part of the crust would suffer tension and foundering; during heat escape, solidification, and contraction, support would be withdrawn from the outer crust, which would suffer from severe lateral pressure and would collapse, crumple, and crush, especially at the margins of the continents and the edges of the shelves which separate these great features from oceanic depressions.

Professor Wegener makes a suggestion, not incompatible with Joly's theory, that the superficial crust of the earth is capable of movement on its plastic or liquid sub-stratum, and that there is a " drift " of land masses towards and away from each other, due in part at least to the action of " solid tides ". By such drift he would explain the breaking up of continents, such for example as that on which the Permian glaciation occurred, the ridging up of the crust where the drifting masses " strand ", and the curious fact that the opposite sides of such an ocean as the Atlantic would almost " fit " if brought together. Attractive as such a hypothesis is, it is in need of a much more severe test by application to facts than it has yet undergone.

Laying theory aside we may return to admitted facts. The earth crust has been growing increasingly complex in structure. Once made by the packing together of rocks, a mountain-mass becomes a " mole " against which break the waves of the next period of movement; and though each range in its turn becomes mown down by denudation its roots remain as a corrugated and strengthened " knot " in the crust. This increasing complication has not only produced and guided the relief and beauty of the earth's surface, but it has introduced greater variety

into the conditions of life and has forced the pace of organic evolution.

During what may be called the indigenous evolution of the earth itself, events have also been developing outside the planet and impressing their mark upon it. There is continual tidal stress, the precession of the equinoxes, the revolution in space of the earth's orbit round the sun, the slow change in the shape of that orbit, and the possible variation in the output of solar energy. All of these react upon the earth, but their effects are hardly likely to be recognizable by themselves, only in their reinforcement or diminution of the results of terrestrial activity. The great variations in climate which the earth has passed through—climate at one time uniform, at another diverse; sub-tropical in British latitudes in the Eocene, and glacial in the same region in the Pleistocene Period—are likely to present an extremely complex rhythm according to the " interference " of cosmic causes with land elevation and movement, and their joint effects upon the currents and other movements of the ocean. Such climatic changes have in their turn reacted continually upon the evolution of life.

The study of the Geological Record reveals many other evolutionary changes which can only be hinted at. Evolution of types of igneous rocks proceeding in the earth's interior, and their effect on the successive changes in volcanic activity; the evolution of sediments due to conditions of erosion, trans-port, and sorting; the evolution of land-forms and landscape, of relief and contour, summing up all the agencies that have affected them since their component rocks were made; the evolution of the mineral and fuel wealth of the world; and, not impossibly, the growing change in the composition of the ocean itself, due to the gradual accumulation within it of a reserve of material which is not being used as a medium of exchange between the forces of destruction and deposition and the living inhabitants of the sea.

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CHAPTER IV

Biology

"The biological sciences are those which deal with the phenomena manifested by living matter; and though it is customary and convenient to group apart such of these phenomena as are termed mental, and such of them as are exhibited by men in society, under the heads of psychology and sociology, yet it must be allowed that no natural boundary separates the subject matter of the latter sciences from that of biology. Psychology is inseparably linked with physiology; and the phases of social life exhibited by animals other than man, which sometimes curiously foreshadow human policy, fall strictly within the province of the biologist.

"On the other hand, the biological sciences are sharply marked off from the abiological, or those which treat of the phenomena manifested by not-living matter, in so far as the properties of living matter distinguish it absolutely from all other kinds of things, and as the present state of knowledge furnishes us with no link between the living and the not-living."

Introduction

These opening paragraphs of the article " Biology " in *The Encyclopædia Britannica* (1910), which stands over the initials of Thomas Henry Huxley and P. Chalmers Mitchell, may serve as a departure platform. Their aim is to delimit the province of inquiry to which the adjective " biological " is applicable. The stress is on natural boundary. We are told on the one hand that " it must be allowed " that the province of biology is inseparable from that of psychology; but on the other hand it is stated that the biological sciences " are sharply marked off from the abiological ". In terms of natural boundary, then, there is only one such boundary—that which delimits the living from the not-living.

This natural boundary is, I take it, drawn on what are commonly spoken of as empirical grounds of observation and inference. " The present state of knowledge furnishes no link between the living and the not-living." The word " link ", and the expression " natural boundary ", are no doubt metaphorical; and, brought together, the metaphors savour of mixture. Let us try other metaphors. Picture the boundary between two adjoining fields—each peopled by some specific assemblage of natural events—as a stream. Then we may get from one to the other by a bridge, or by means of a row of stepping stones, or by leaping across the stream. Over the bridge we may wheel a barrow or, let us say, continuously slide. By means of the stones we proceed by steps, each of the nature of a little jump. The leap is just a greater jump. On these terms then there is, it is said, no bridge between the living and the not-living. In the present state of our knowledge (1910) there is no good evidence of stepping stones. If, therefore, natural events have somehow and somewhen got across from one side to the other, we must accept a great leap—a leap of such a kind that " the properties of living matter distinguish it absolutely from all other kinds of things ".

Now what about other assemblages of events in sub-fields of the abiological province of inquiry? As I read the evidence, the streams at their boundaries are jumped by clusters of events which in each new field forthwith exhibit new qualities and properties. There are many such jumps. I do not say that there are no bridges; but I submit that the advance of nature which brings with it really *new* features is by steps, or by leaps, and not by sliding over bridges. It is my belief, then, that in the broad domain of nature, from bottom to top, natural leaps are many—so many that I have ventured on occasion to speak of the advance of nature as fundamentally jumpy. This may no doubt be shocking to those who yearn for continuity. But one must speak as one finds after survey of what one judges to be the relevant evidence. And since the delimitation of biology from physics and chemistry which I submit for consideration turns on the hypothesis of an orderly step-like advance—since,

too, the place of life in that which is an evolutionary scheme (in one sense of the word " evolution ") is thus determined—a brief statement of the grounds of my belief will not be out of place. It will show what I mean by evolution.

Emergent Evolution

We must begin near the foundations of the physical world far down in the abiological province of inquiry. What do I mean by speaking of nature in this primitive region as " jumpy" —if this colloquial word be permitted? In reply I must briefly refer to that which is discussed in technical terms as the " quantum theory ". It is difficult for most of us to grasp; and it is not my business to do more than adduce what seems to be pertinent in illustration of what I mean. If one ask a physicist to tell the story of the hydrogen atom he may ask: Which of some thirty of them do you mean? Picture, he may say, the negative electron as in orbital motion. There is *for mathematical construction* a continuous set of possible orbits, say from the narrowest to the widest as limiting concepts; but it seems that only a discrete set of orbits is *actually given in nature* for the physicist to deal with. As Poincaré said: " A physical system is only susceptible of a finite number of distinct states; it jumps from one of these states to another without passing through a continuous series of intermediate states ". With each jump of the hydrogen electron, there is emitted an electromagnetic wave. The discontinuous spectrum of an assemblage of hydrogen atoms is a visible expression of the actual jumps that occur.[1]

The ascending series of " elements " (including the " isotopes "), from hydrogen to uranium, exemplifies discrete steps in a manner so familiar that bare mention may here suffice.

What, then, of the molecule and the crystal? Sir William Bragg tells us that the crystal unit, say of quartz, consists of three molecules of silicon dioxide " arranged in a particular

[1] Cf. *Concepts of Continuity*, Aristotelian Society, Supplementary Vol. IV. *Symposium on the Quantum Theory*, pp. 19–49.

way ". What, then, is the molecule of silicon dioxide? In it there are atoms of silicon and oxygen. They too go together in a particular way. And what of each atom? In it there are negative electrons in specific relation to a positive centrum; and these also go together in a particular way.

Thus we have certain primitive electronic events, as items of what we may call " stuff ", which go together in substantial unity (or briefly in " substance ") to constitute the atom. Each atom is an orderly cluster of events; and such clusters, as new and higher items of stuff, go together in a new kind of substantial unity to constitute the molecule. Molecules, as yet more complex items of stuff of higher status, go together to constitute the crystal unit, new in substance, or the inorganic colloidal unit which differs in its mode of substantial unity.

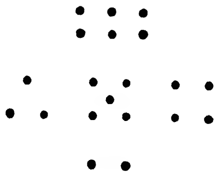
There is thus progressive advance (*a*) in the complexity of the higher units of stuff and (*b*) in that which may be spoken of as richness in substance. The items of stuff as events or clusters of events are many and are distributed; but the substantial unity in any integral entity is one and indivisible. It pervades the entity as a whole and ties together by invisible bonds the multifarious items of stuff which, taken severally, are its parts.

So far we have what Sir William Bragg speaks of as different " types of assemblages of matter ", at different levels or stages of advance, in the province of abiological inquiry. There seems to be a jump from level to level; and with each jump new properties " emerge " in orderly and determinate progress. Such progress is evolution, in the sense of the word I accept. I speak of it as " emergent evolution ".

A quite diagrammatic illustration may be helpful in rendering this interpretation of natural events in some measure comprehensible. Let certain primitive items of stuff be represented by five dots. If they be distributed " anyhow " there is no assignable " substantial unity " in the random collection of dots. There is no " integral entity ". But let them be quite

definitely arranged in some orderly fashion, say thus • • • • •, or thus • • • • •, or thus • • • • •; then in each there is substantial unity in plan. Each, then, is an " integral entity ", like to the others in the number of its similar items of stuff, but differing from others " in substance ".

When matters get a little more complex we may have diagrammatically something like this



where each orderly sub-group of dots represents an item of stuff " of higher order ". Thus we may proceed upwards to increasing complexity of the items of stuff, with increasing richness " in substance ", or in unity of plan. One may, so to speak, point the mental finger to any given item of stuff and say that it is just here in the entity or there. But the substantial unity of plan is *everywhere* in the sense of pervading the whole entity throughout its entirety.

Add now this further concept—based, as I think, on the evidence afforded by natural entities—namely that on each substantial change of plan (with a jump) new qualities characterize the new integral entity. Then you have in a diagrammatic nut-shell what I mean by " emergent evolution ".

In Search of Abiogenesis

Now when we pass from the abiological to the biological province of inquiry what seems to be in evidence is a new plan of very complex natural events as items of stuff raised to a higher emergent level in new modes of substantial unity. It comes with a jump, or somewhere in an enchained series of steps, each analogous to (not of course the same as) that from atom to molecule, or from molecule to crystal or to colloidal

unit. It has new properties different from those observable at any abiological level. It is no longer physico-chemical only.

So far, the delimitation of biological from abiological inquiry is not discordant with that given in *The Encyclopædia Britannica*. There is no denial of a jump from lifeless things to living things; there is no disregard of the quite new properties which emerge with the jump from the inorganic to the organic; there is acceptance of that which is thus implied, namely that biological events are not susceptible of interpretation in purely abiological terms—those of physics and chemistry only.

Stress is, however, there laid on the present state of our knowledge in 1910. And we must ask whether the state of our knowledge in 1925 throws any fresh light on " linkage " in some sense of this word, or, as I put it, on an orderly series of steps in advance. Permit me to revert for a moment to an abiological series. Take that of the atomic order. There seems to be an advance from hydrogen to uranium with so-called storage of energy (" winding up ") as we ascend, though there are three or four " missing links " in the present state of our knowledge. There are orderly steps from each atom to the next, each of which is a resting-stage in a natural order of sequence. Many believe that there was a time when the natural conditions were such that the later steps had not yet occurred; and it is at least a probable hypothesis that uranium has been reached by a natural chain of progressive steps. But it may be said that this, even if probable, has not been proved—nay more that it will not be proved until uranium has been built up step by step in some physical laboratory. Such seems to be the severely critical attitude taken up by many people with regard—not perhaps to uranium, for that, they may say, does not much matter—but with regard to living organisms.

It need hardly be said that this parenthetic reference to the atomic series must not be taken to imply that the living organism is just one step higher than uranium and is a member of the atomic series. It is much more than that; it is a natural entity with biological and not only abiological properties. It is a living thing. Why then is the atomic series introduced? To

illustrate the general principle that in the present state of our knowledge we must work piecemeal at the several steps, and that it is scarcely reasonable to expect that the sequence as a whole should be reproducible in any scientific laboratory.

In the older approach to the problem of the origin or genesis of living things, the question took this form: Is there always that enchained continuity in life-heritage which was spoken of as biogenesis; or is there, on occasion, a leap upwards from the not-living to the living in " spontaneous generation " or abiogenesis? The verdict was for biogenesis. In the then state of scientific knowledge there was no evidence in support of abiogenesis. Hence in those days the most that could be said was that " those who take a monistic view of the physical world may fairly hold abiogenesis as a pious opinion, supported by analogy and defended by our ignorance. But, as matters now stand (1886), . . . no claim to biological nationality is valid except birth."[1]

The question then arises whether since 1886—and in large measure since 1910—more recent inquiry on rather different lines has supplied presumptive evidence of an orderly series of stepping-stones across the " boundary " between some abiological field of events and a field of events in which biological properties supervene. It is a highly technical matter and introduces concepts with which the layman, and indeed many biologists, are unfamiliar. In terms of stepping-stones, may we regard as such (1) the formation of formaldehyde with liberation of free oxygen; (2) polymerization to give simple sugars such as hexose; (3) the introduction of nitrogen into more complex molecules under the influence of light of short wave-length, acting on nitrates in the medium, with production of intervenient nitrites? If so, this is only one of several concurrent and conspiring lines of advance. There is also that of the development of a suitable colloidal substratum. Here we are faced by concepts of ionization, adsorption, surface tension, and the like. We have to consider how " metabolic gradients " with incipient " polarization ", say under differential incidence

[1] Huxley, *Essays*, Vol. I, p. 117.

of light, and alternation of day and night, first arise; what is the office of photocatalysts and what their relation to enzymes; how correlative differentiation of function and structure (now commonly regarded as inseparable) may be interpreted; and much else. The bewildered layman may say that he understands scarcely anything from all this technical jargon. If he seek to do so let him grapple with Dr. Church's *The Building of an Autotrophic Flagellate*, or at least read Dr. Allen's Presidential Address to the Zoological Section of the British Association (Hull, 1922) on *The Progression of Life in the Sea*.

What then is the present position? It seems that, although the complete chain of steps in this extraordinarily difficult borderland inquiry cannot be reproduced under laboratory conditions, still some of the many " links " in such a chain are coming piecemeal within the ken of scientific knowledge. It seems, indeed, increasingly difficult to indicate any one crucial step which may be indicated as *the* jump upwards to a living being. On the other hand fresh light has been thrown on the nature of some of the processes—not physico-chemical only—which betoken life, and new avenues of detailed inquiry are progressively opened up.

There we must leave the matter, emphasizing only three points of general import. (1) There are those who claim that, if the circumstantial evidence for an unbroken sequence be established, this will show that there is no natural boundary between the lifeless and the living. It may be said that a biological field of events in the organism is nowise essentially different from a physico-chemical field save only in so far as the phenomena, therein, present added complexity. So-called jumps are only apparent. There is a smooth slide upwards to life. We are beginning to descry a continuous bridge. (2) There are those who hold that a critical review of physico-chemical processes, as they occur in integral entities, increasingly favours the concept of step-like advance with the sudden appearance of *new* characters. Hence they contend that there arises at some stage a substantial difference which still justifies a valid distinction between the living and the life-

less. But it is a distinction that has arisen within one natural order of events. (3) There are those who contend that no such concept as natural advance from the not-living to the living is admissible in any valid sense. The life of an organism belongs, they say, to an order of being wholly different and disparate from that of what are commonly called natural events. Life is not the outcome of the evolution, so-called, of organization. It imparts those modes of organization which the biologist observes.

Which of these three hypotheses is to be accepted? All that one can say is that one or other *is* accepted, in all honesty, according to what this or that inquirer deems the preponderant weight of the available evidence. My personal opinion is that the weight of the evidence is in favour of (2); but others hold different opinions. So be it. Let each state as clearly as possible the view that seems to him best.

Biology and Psychology

Thus far attention has been directed to what one may speak of as the lower limit of biological inquiry. Is there an upper limit? Does one, on the hypothesis of upward steps (under 2), reach in due course a jump from the subject matter of biology to the subject matter of psychology? It will be remembered that, according to *The Encyclopædia Britannica*, "it must be allowed" that no natural boundary separates the field of inquiry in psychology or sociology from that proper to biology. What are we to understand by this? Does it mean that, in discussing the growth of a plant or the embryonic development of the chick, we must introduce psychological concepts in the generally accepted sense of these words? I think not. It means that at a certain stage of biological development we may (at our hazard) infer that something of the nature of conscious enjoyment and something of the nature of cognitive reference accompany certain highly differentiated physiological processes. In other words there is at some given phase of life-advance, some sort of "mental" accompaniment of certain bodily events. Hence that which for the biologist is a complex set

of physiological events in the cortex of the brain, is for the psychologist a set of no less complex psychological events in the mind. *These* events are items of stuff in the substantial unity of the total physiological poise; *those* events are items of stuff in the substantial unity of the total mental poise. As the psychologist may put it the mental items go together in the substantial unity of " meaning " which is correlated (though this may be roundly denied) with the substantial unity of the organism.

Now, giving this pervasive substantial unity full weight, we may widen this concept of correlation. As I put the matter above, it is restricted to *some* physiological events of a highly specialized kind in the cortex of the brain. Let the concept have unrestricted range. Then we may conceive *all* physiological events, e.g. in the amœba or paramœcium—nay, even those in the fertilized ovum or the acorn—as having mental concomitants which only the entity itself can experience or enjoy. I use the word " mental " in its widest and most comprehensive sense.

On this view, which is a speculative extension of that hypothesis of restricted concomitance or correlation which is provisionally accepted by many biologists, there is no " boundary " that separates events which just *are* physical and physiological in one regard and mental in the other regard. This leaves the biologist free to pursue his inquiries in that which, as some of us think, is his own proper field of work. He does not deny (let us say in human folk) the presence of psychological motives with reference to future action. He says only: What for you, as psychologist, are motives with *future reference* are for me, as biologist, physiological events with *present influence* on the course of other physiological events in the body. He does not say—or I think that on this view he ought not to say: Such and such physiological events are *the cause of* such and such mental processes. Nor should he say: Such and such motives are *the cause of* such and such bodily changes in behaviour. He should, on this view, be content to say: Such and such events of the one kind *accompany* such and such events of the other kind.

And he may hyphen the events as psycho-physical, or psycho-physiological, or perhaps psycho-biological.

There is, however, an alternative view. On this view the events which stand on one side of the hyphen *are* in causal relation to those which stand on the other side of the hyphen. I am well aware how difficult it is to render quite clear what we are to understand by cause and effect. But most of us know what is meant by saying that some bodily process, say in the eye under stimulation by light-waves, causes the mind to perceive a red billiard ball in line with one's own ball and " spot "; and by saying that the wish to make a cannon off the cushion is the cause of our using the cue in a certain manner. On this view there is interaction of the external world through the bodily sense-organs on the mind, and of the mind through the organs of behaviour on the external world.

It may quite justly be said that such " impartial dualism ", as Mr. W. E. Johnson calls it, is in large measure the view of unsophisticated common sense when we are dealing with the current affairs of human life. To reach an end in view that is suggested through perception of the existing situation, more or less mental endeavour causally intervenes between stimulation and responsive behaviour. On these terms common sense explains much that happens hour by hour throughout the day. But does common sense deny that there is a continuously enchained series of bodily events between those that accompany seeing the billiard balls and those that accompany making the stroke? Let common sense make reply. I hazard the guess that not all common-sense folk feel justified in denying such an enchained series of bodily events. Many of them may say: I really do not know enough about the matter, which seems to me rather technical, to say whether it is so, or is not so. Physiologists tell me with assurance that it is so. But some philosophers assert with no less confidence that it is not so.

The position as I view it is this. Between seeing the balls on the billiard table and making the stroke is what the psychologist calls " meaning ". This word may be taken in two closely allied senses. There is what the situation " means "

for one who has learnt to play billiards. And there is " meaning " in the sense of intending to get a cannon off the cushion. The question then is: Are there brain-events which accompany this two-fold " meaning " in mind? Some say: Yes, there are. Others say: No, there are not. Those who say that there are *not* accept causal interaction between body and mind. For if " meaning " intervene to occupy a gap in the bodily sequence of events; and if the whole series be in continuous causal relation; it is clear that such relation must obtain between the physiological events on each side of the gap and the mental processes which fill the gap.

Common-sense may well say that this is a technical matter. I cannot follow it up further here and now. I will only ask two further questions. Does not the interactionist regard " meaning " as substantial unity in affairs of the mind? May not the physiologist, on his part, contend that, accompanying this substantial unity, there is correlative unity in affairs of the body? On this understanding there may be *one* substantial unity in the mind as embodied and in the body as enminded. But we must not expect to be able to put our finger on it here, there, or elsewhere, since it pervades alike the whole mental system and the whole bodily system. Such is the nature of substance.

Even so, however, there remains a crucial issue. Does the course of events which we discuss under the heading of mental process in some sense " determine " the course of events which we discuss under the heading of physiological process; or does the " determination " run the other way? Opinions differ. And it is well to make quite clear that there does exist this radical difference in philosophical opinion. What I propose to do (thus pleasing neither party) is to avoid, so far as is possible —one cannot wholly avoid—this very vexed speculative issue. I propose to consider how things will work out if we say that two stories may be told with regard to the living organism—one story in biological terms of what happens to or in the body, and another story in psychological terms of what processes go on in the mind. I suggest that we should accept these two stories as closely connected—since all admit that there is *some*

kind of connection between body and mind—without asserting that the events with which one story deals are either the cause or the effect of the events with which the other story deals. And I suggest that each story should be discussed on its merits in accordance with the best available evidence. This implies, with regard to the psychological story, that we should not attribute to any organism lower than ourselves psychological processes such as occur in human folk without good evidence (or, strictly speaking, inference based thereon) that the mind of that organism has reached the level at which processes of this kind do actually play their part in the psychological story.

It may be said that in a Chapter on Biology I ought, on the principle of interpretation above suggested, to keep to what I call the biological story and to that only. But as matters stand—especially as matters have developed of late—the two stories are very closely interwoven; so much so that we are told that we can only interpret the biological story aright when we regard it as a psychological story, to be told in terms of such distinctively mental concepts as perception, end in view, and endeavour to reach that end through appropriate behaviour. So far as I can judge this " new biology " advocated by Professor J. Arthur Thomson in his *System of Animate Nature* (1920) just now bulks large to the eye of the general public interested in such matters. For this reason it should be considered with some care since it comes in effect to this: One cannot tell a biological story save in psychological terms.

Psycho-biology

In human conduct, even in the behaviour of the very young, when what I shall speak of as " plans in mind " have taken or are beginning to take form, we are fully justified in inferring the presence of endeavour with prospective reference to an end in view. As a trivial example take the advertisement of Pears' Soap with the legend: He won't be happy till he gets it. There is an actual state of affairs, and (inferentially) a different state of affairs, dimly or clearly envisaged in the child's mind. The actual state of affairs is then and there present; the different

state of affairs, as end in view, is, in a sense, absent save as thus envisaged. Such envisagement of what is not yet in being—and in that sense is absent—with a wish that it should be actually present, implies in the given situation, perception, purpose with prospective reference, endeavour and, let us hope, satisfaction in fulfilment, on the part of the child. All this, if it really does go on in the child's mind, is quite distinctively psychological. But there is also a biological story (which most of us take for granted) to be told in terms of stimulation and response, with an enchained series of physiological events.

Can some such story be told of a lowly animal, an amœba for example, or of a plant? Can it be told of a fertilized ovum, or an embryonic chick? Dr. E. S. Russell, as advocate of what he names "psycho-biology", says that it can and should be told.[1] Speaking of an amœba, that, when it is suspended freely in mid-water, sends out long pseudopodia in all directions till it reaches something solid on which it can glide, Dr. Russell says that, "considered psycho-biologically this implies perception by the animal of the absence of the usual stimulus supplied by the surface upon which it normally moves, implies memory therefore. The perception goes over into an impulse toward movements of a type calculated (not of course consciously) to restore the normal situation. . . . In the same way, a plant bulb in a hyacinth glass sends out long roots in a vain effort to find the earth and to burrow into it. . . . The list of parallel cases could be extended indefinitely. . . . Considered psycho-biologically they imply perception of the absence of support and an effort directed towards remedying this lack."[2]

If a play upon words be permissible, there is something *wanting* in the existent situation; this is perceived by the living being; but it is also *wanted*; active endeavour supplies what is "wanting" and thereby gives what is "wanted". This psycho-biological concept is applicable to "the interpretation of those deeper manifestations of life which we know as development, differentiation of structure and function, and

[1] *Proc. Aristotelian Soc.*, 1922–3, pp. 141 ff. [2] Op. cit., pp. 148–50.

functional adaptation. . . . They may be regarded as directly analogous to behaviour-responses for the reason that they show the same objective characteristics, namely the ' whole-action ' of the organism, active tendency or striving towards an end, and adaptability to circumstances ". Hence life is " regarded as a continuous process, manifested by individuals which strive actively, albeit blindly, to achieve in spite of circumstances the end and aim of their being ".[1]

In his recently published book on *The Study of Living Things* (1924), he enlarges on this theme. In further reference to the amœba and its allies he cites the observations of Messrs. A. A. Schaeffer, Kepner, and Edwards. From them it seems clear that the rhizopod reacts differently to two types of food; in a simpler manner to those food-objects " that do not set up currents in the surrounding water and that do not present the contingency of escape "; and in a more complex manner " to forms that set up currents in the surrounding water and that do present the contingency of escape ". Here with difference in mode of stimulation there is observable difference in response. " The animal will react to any localized source of water-vibrations as if to a motile prey, provided these vibrations resemble those set up by a normal prey." But the inference seems to be that the rhizopod meets " the contingency " by choosing the more complex mode of response. It is a " contingency " for the rhizopod no less than for the observer.

In any case " it is clear . . . that it is not the stimulus *per se* that is reacted to, but its significance ". Now significance is a distinctively mental concept. The interpretation is therefore psycho-biological. " What is responded to is not the stimulus *qua* physico-chemical, but the stimulus as perceived; and not the stimulus merely as perceived, but as interpreted." Hence " the first aim and object of research " should be " the discovery of the meaning of the presented situation, and the extent to which single elements of it may be treated as symbolic [for the amœba, as I understand] of the whole situation ".

[1] Op. cit., p. 152.

It is, however, a little difficult to realize exactly what is supposed to go on in the mind of the amœba; for we are told that " no hypothesis as to the inner experience of the organism is implied, and in particular it is unnecessary to assume any actual conscious willing of response with foresight of the end ". We seem, then, to be brought into the very debate-ful region of " unconscious wishes " on the part of the amœba.

And in this region one wonders whether such words as " end " and " intention " (often " objective intention ") are used in their older psychological sense or in some sense special to the " new biology ". I suppose most of us, whether " old " or " new ", would say that the observable *outcome* of certain modes of excitation of the salivary glands is a flow of saliva; and that the *outcome* of salivation may be some change of the food in the mouth. But more than this seems to be implied when we are told that " the sight of food elicits a salivary response which is firstly a muscular but finally a chemical response, and has certainly a chemical end or intention ". And yet, here again, one may feel a little doubtful as to what the psycho-biological interpretation really amounts to; for we are told that when " once we leave the domain of animal behaviour, psychology is not going to help us in the study of organic responses ".[1]

The Hormic Schema

Why, then, the reiterated insistence on the cardinal principle that all biological explanation should be couched in psychological terms?

Here arises the difficulty in avoiding philosophical or metaphysical issues. From first to last Dr. Russell harps again and again on these issues. What he is concerned to combat is that which he speaks of sometimes as the " mechanistic schema ", sometimes as the " deterministic schema ". By these, he thinks, biologists have been too much " obsessed ". In their place he

[1] Op. cit., pp. 63–81, 84, 97.

accepts what may now be called the "hormic schema".[1] Here, what is central is urge (*hormé*), or drive, or *élan*. But the urge drives forward towards its end. Hence there is a "teleological" factor even in the acorn whose end is to become an oak tree, or in the fertilized ovum whose end is to become a rabbit or a star-fish, as the case may be. Furthermore the urge towards an end implies memory, in the Bergsonian sense, as veritable storage of the past—implies therefore a so-called mnemic factor, in a sense radically different from that in which the word "mnemic" is used by Semon and his followers where it implies only some change in the organism (an "engram") which was wrought in the course of its past history and is retained as a structural change in the body. The cardinal contention, then, is that all biological phenomena should receive "hormic" explanation, a kind of explanation that is neither required nor applicable under the schema of mechanism which may be appropriate enough where we are dealing only with abiological phenomena. Moreover a hormic schema implies freedom of choice of means by which the end shall be attained; it differs, therefore, in this respect also from a rigidly deterministic schema.

Now in the matter of urge, the pivot of the whole schema; in the matter of end in some manner present in mind before the outcome of current action is reached; in the matter of the retention of the past and not only of changes in the organism retained from then till now; in the matter of determinism or indeterminism; we are in the thick of philosophical or "metaphysical" problems which are not only debatable, but are debated with no little warmth and often with a good deal of acrimony. I suggest that we should emphasize further the usage already coming into vogue and should label quite distinctively as *hormic* the philosophical creed which centres round urge as a kind of activity altogether *sui generis*. One might speak of those who advocate such a creed as *hormists*. But, if we do so,

[1] P. 56. Cf. T. Percy Nunn, *Education: Its Data and First Principles*, p. 21; also W. M'Dougall, *Outline of Psychology*, p. 71, "The Hormic Theory".

let these words be used without that touch, or more than a touch, of opprobrium which some writers seem unable to refrain from importing into the words " mechanism " and " mechanistic " or perhaps " behaviouristic ". Dr. J. B. Watson and Professor M'Dougall both claim to build upon behaviour.[1] But the one is a hormist, and the other repudiates a hormic schema. Professor M'Dougall's treatment of instinct is hormic throughout; Professor Percy Nunn bases education on hormic principles; Professor J. Arthur Thomson is hormic to the core. If then I speak of Dr. Russell as concerned to advocate a hormic schema I intend no shadow of disparagement. He is in quite good company. One should at least respect if one cannot share the convictions of others.

For we are in the region of conviction—strong and sincere conviction—attaching to a philosophical creed. It is questionable whether one can wholly avoid all discussion of these deeper issues. But one may try to distinguish them. I hold that there is a biological story of bodily events, and that there is a psychological story of mental events. But there is also a third issue. Here the question is raised why it is that there are these two stories, or how it comes about that they, and the stage on which they are enacted, are there for the telling. I propose to take that which I think is the scientific, as distinguished from the more strictly philosophical, attitude in saying: There they are for the telling; and they are what they are however they came into being on hormic principles or otherwise. Let us tell them as clearly as we can in the light of the best available evidence.

The trouble is that this or that writer's philosophical attitude with respect to what may be called the metaphysical issue is apt to colour his manner of telling the biological story and the psychological story. Dr. Russell, as a faithful disciple of M. Bergson, accepts as a cardinal tenet in his creed, that " mechanism " is irretrievably static or momentary and can therefore " take no account of continuance, development, the persistence of past experience, or adaptability " *as hormically defined.* Hence there is, of course, " no intermediate view-

[1] Cf. *Psyche*, Vol. IV, No. 1 (July, 1924), p. 17.

point ". Under definition there is either mechanism and no development, or development which is other than mechanism. But Dr. Russell (in his " Aristotelian " paper) is commenting on a passage in Sir Charles Sherrington's Presidential Address to the British Association (1922); and it is quite obvious that in this address the word " mechanism " is not used in contradistinction from development. As the word is there used it names the structural provision in the organism for functional processes (including those which are accompanied by mental processes) that occur therein. It is in this sense that he seeks the mechanism of development and of other life-processes. He frankly confesses, as must every honest inquirer, that there are many processes (some of them on my hypothesis characteristically emergent) the structural provision for which is at present very imperfectly known. Thus, within the fundamental unity of the living creature, animal or plant, " the shaping of the animal body, the conspiring of its structural units to compass later functional ends, the predetermination of specific growth from egg to adult, the predetermined natural term of existence—these, and their intimate mechanism, we are, it seems to me, . . . still at a loss to understand ".

Here speaks the man of science, using the word " mechanism " in a sense that is readily comprehensible, but without the metaphysical implications of a " mechanistic schema ", static or dynamic. But Sir Charles Sherrington uses the words " predetermination " and " predetermined ". Does this imply the acceptance of a " deterministic schema "? It may or it may not. I hazard the opinion that it does not. The vexed question of determinism or indeterminism is a metaphysical issue of far-reaching importance. The acceptance of one or the other is in large measure rooted in conviction which lies much too deep to be affected by argument. In what sense, then, may the word " determined ", like the word " mechanism ", still be used without metaphysical implications? I submit that it is commonly used where certain events in their particular or individual occurrence are judged to be connected in such wise as to conform to some general (or technically " universal ")

plan of events of this kind. When Sir Charles Sherrington speaks of " the predetermination of specific growth from egg to adult " he may be taken to mean the conformity of the development of this or that chick or rabbit with the general plan of such development in chicks or in rabbits. There are, as we have been led to believe, in organic nature such *de facto* plans of the course of events in normal routine. Some of these plans the biologist has discovered, just as the physicist has discovered the plan of this or that atom, or molecule, or crystal, each after its kind. For him, as biologist, they are "plans in mind"—his mind. But the plan, at first hand in nature, or at second hand in the mind of the observer, does not make the events what they are or as they are. At any rate they do not do so under the method of interpretation which I regard as scientific. But the hormist contends that something which is very difficult to distinguish from " a plan in mind " on the part of the embryo chick or rabbit does freely determine the course of events in specific growth from egg to adult. This, I urge, is a metaphysical hypothesis which goes beyond biology or psychology as departmental branches of science; and, whether this hypothesis be valid or invalid, the course of events in accordance with natural plan remains quite unaffected. Hence I feel justified in relegating this further issue, important as it no doubt is, to a suspense account for audit under metaphysics.

There is one other feature of the hormic schema which calls for comment, namely the stress laid on *activity*. This emphasis is common to all those who follow Professor James Ward in his insistence on conation as the exemplar of such activity.

Now although biologists not infrequently speak of activity (e.g. that of the cerebral cortex or that of the thyroid gland), what most of them, or at any rate many of them, mean is no other than *action*. With regard to such action, and the use of the adjective " active " in connection therewith, few are prepared to dispute. Indeed one may say that there is nothing to provoke disputation. In physics both words, " action "[1] and " activity ", often occur. But here activity does not imply

[1] Cf. *Concepts of Continuity*, p. 37.

an "efficient cause" to which action may be due. Would it not be well to earmark the word "activity" for use, in philosophical discussion, under *this* connotation? If we do so then, as all students of philosophy are aware, there is disputation enough and to spare. Pages and pages have been written, and more no doubt will be written, on this side and on that. Some roundly assert, others as roundly deny, that they, or any others, have immediate experience of *such* activity; but no one denies that we have experience of action in progress. I submit, then, that this disputable and often disputed issue should be relegated to the metaphysical suspense account. Hormic urge is quite clearly a species of this generic concept of activity. The hormist is an *activist* and not only an *actionist*.

On these terms we have to deal with organic modes of action in the biological story, and with their mental accompaniments in the psychological story (so far as it can be told); and we may leave activity (which, for me, always connotes Spiritual Activity of which emergent evolution is the "manifestation" under the conditions of "time and space")—we may leave this out of account in a chapter on biology.

Two Stories Distinguished

My aim, then, is to distinguish two always concurrent stories—a biological story and a psychological story. I proceed on the hypothesis that in respect of any given organism there *are* two stories (or if it be preferred a twofold story) for the telling. In that sense what has to be considered is the psycho-biology of living beings, as enminded bodies or embodied minds. But the trouble is that whereas the biological story is based on that which can in large measure be viewed from without, the psychological story is founded on inward introspection. Our own current modes of experiencing afford our only clue to modes of experiencing in others; and in so far as we impute or attribute some such modes of experiencing to others, we must do so with due caution, drawing our inferences from the best available evidence.

Now in discussing our own mental life there are sundry distinctive concepts that psychologists of all schools make use of within their province of inquiry. Among these are perception, expectation, memory, end in view, impulse, motive, purpose, endeavour, and the like. Each of them needs careful definition; and they *may* be so defined as to carry hormic implications with central stress on activity. But it is plain matter of history that many distinguished psychologists define them, one and all, without any such implications. It is clear, therefore, that those whom I have called hormists, those whose philosophy demands urge, *élan*, driving force, so-called mind-energy, and the like, can claim no monopoly in the use of any of these psychological concepts. All that they should say—and this they have every right to say—is: What you define as endeavour is not endeavour as we define it. And yet, though there is this wide divergence of view as to the philosophical significance of the mind-story, the story itself, for example the story of human endeavour, remains much the same. My aim is to get at the story itself apart from its philosophical implications whatever they may be.

It comes, therefore, to this: If we be content to say that the stories are *in some way* connected, leaving the nature of the connection open for philosophical discussion; if we be content to say that each accompanies the other in the course of nature; if we refrain from saying that the events recorded in either story are the cause of the events recorded in the other story; if we refrain also from saying that the events in either story do not count for progress (are merely " epiphenomenal "); then this or that living being is in one regard an integral system of physiological events, and in the other regard an integral system of mental events. In both regards there is substantial unity in virtue of which the living being is veritably one system. This one system the physiologist studies in one regard, while the psychologist studies it in the other regard.

Now if we identify biologist with physiologist it may be said that, on this showing, the biologist, as such, should keep to the one story, leaving the psychologist, as such, to keep to

the other story. But is this practicable? Some of us still look up to Darwin as among the greatest of biologists. Did he tell one story quite irrespective of the other? Can any zoologist who deals with birds and mammals (to go no lower), either in the routine of their daily life or in the history of evolutionary advance, disregard the part played by their " powers of perception ", their " intelligence ", and so forth?

Let us here pause to distinguish biography from biology. In the sense intended biography is purely descriptive, while biology offers an interpretation of that which is observed. In the biography of many birds the males in northward migration arrive before the females; each male " secures a territory ", sings therein, is joined by a hen-bird, and in due course mates with her. A nest is built, eggs are laid; after incubation young are hatched out, and are fed by the parents; they grow, become fledged, and in due course fly. Later in the season parents and young depart in southward migration. Here from first to last throughout this episode in life-history we have description under careful observation. We thus get, as we say, the facts so far as they can be ascertained. But few rest content with bare facts. They seek to interpret the facts. Biology, as distinguished from biography, is interpretative and not only descriptive. I suppose nine field naturalists out of ten interpret in terms of what they call common sense. What goes on in the egg during incubation, growth, the development of feathers, and so forth—all this, they say, is just organic process which the physiologist can describe. But there is much more than this, which in accordance with common sense should be interpreted in terms of what we know of human procedure suitably modified to meet the circumstances of bird-life. But the tenth may try to interpret more adequately, namely in terms of the fullest up-to-date knowledge of processes in the body, and of the fullest up-to-date knowledge of mental processes. Common sense is seldom up-to-date.

Now I think that as some use the word the former interpretation is biological, and the latter interpretation is psychological; but that, as others use the word, in a more

comprehensive sense, both interpretations are biological. And so we work back to the statement in the *Encyclopædia* with which we started, where it is said, in effect, that one cannot separate psychology from biology, since what we deal with under biology, as the word imports, is life, and life is not only physiological but also mental.

But although in a comprehensive sense that is intelligible and defensible mental processes no less than bodily processes fall within the field of biological inquiry, it is " convenient " to distinguish the biological story from the psychological story; and this because each is told in terms of concepts appropriate to its subject-matter. If we dig down to essentials, the ruling concept in biological regard (as we will henceforward call it) is the physical or the physiological *influence* of " this " event, or set of events, on " that "; whereas the ruling concept in psychological regard is mental *reference* (for example in perception) on the part of that which experiences—say an organism as enminded—to that which is experienced, spoken of as the object of such experience. In the former or biological regard " the entire life of any organism consists of a series of responses to stimuli which reach it from various sources ". In the latter or psychological regard the entire life of any organism is interpretable in terms of the " enjoyment " which accompanies the biological processes, and of reference to something from which physical influence comes, whether directly or indirectly. Such " something " is under joint interpretation the " source " *from* which physical influence comes, and the object *to* which there is mental reference. We must, I think, if we are to relegate philosophical discussion to a suspense account, take physical influence, on the one hand, and mental reference on the other hand, as given in the constitution of the enminded organism. We may use the word " perception " (as Leibniz did) in a very broad sense for the simplest form of reference. On this understanding—for " perception " may be defined as a much higher mental process where there is the added factor of " meaning "—on *this* understanding there is no call to deny that even the plant perceives the light-influence or the gravitative in-

fluence to which it responds. More generally we may say that to any mode of influence there may be a correlative mode of reference, however simple and primitive. From the nature of the case, since we cannot *be* an amœba or an acorn, we may be unable to adduce evidence that this is so; but we should leave open the hypothesis, extravagant as it may at first sight seem, that it may be so. Thus we go as far as we can with psycho-biology freed from all hormic implications.

To illustrate the intimate relation of influence and reference we may take a concrete example from our own daily life. As I write there is (i) radiant influence from the lamp on my table; this reaches the retina of my eyes, and is thence transmitted in a chain of excitations and responses to the occipital cortex of my brain, whence it passes on to other regions of my body when the lamp-shade is readjusted. But there is also (ii) conscious reference on my part to the lamp-light not quite arranged to my liking which I seek to alter by adjusting the shade. We commonly combine the two stories, in commingled terms of influence and of reference. I seek to distinguish them.

A Psychological Schema

The two stories, though distinguishable, are undoubtedly very closely connected in whole or in part. On that matter all are agreed. I believe that they are connected in whole—in other words, as I read the evidence, there is at least strong probability that a biological story always accompanies the psychological story as a whole and in detail. I admit, however, that this is as difficult to prove as it is, in my judgment, to disprove. But on what method of interpretation does the telling of a psychological story turn? There are seemingly different stories in man, monkey, dog, bird, reptile, fish, and so on down to amœba or plant. In what sense different? Different in so far as we attribute to different kinds of organisms different levels of mental, as of bodily, development. On what grounds, then, in purely psychological regard, do we attribute these different levels? On the basis of inference from the behaviour which we observe. What, then, are the psychological

levels or stages of development which may thus be distinguished? Perhaps no two psychologists would give quite the same reply to this question. That which I shall give must be regarded as tentative. But I am bound to give some reply. How otherwise can I bring the two stories into relation? I am not straying beyond the bounds of biological inquiry in the broader and more comprehensive sense. I will try to put my reply briefly. But some illustration is needed to show that I am at any rate seeking to base my conclusions on positive evidence afforded by the careful study of behaviour.

Let us work our way downwards from adult man. Here there can be no shadow of doubt that there is a very complex psychological story—no shadow of doubt that end in view, endeavour, and purpose, in some sense of these words, but not necessarily with hormic implication, are very much in evidence. And I think that, whatever else may need emphasis, stress may be laid on *prospective reference*—not merely Leibnizian perception but the higher kind of perception that carries meaning for future action. No less emphasis falls on *retrospective reference*—on memory, not merely as retention, not merely as revival, but having distinct reference to the past as mentally reconstructed. Combining both forms of reference man forms *plans in mind* which have value in so far as they accord with the plan of the world in which he lives. The plan in mind may be *practical* in that it anticipates the act by which it is realized. The act is rehearsed in mind before it is executed in deed. At a higher stage of mental development the plan in mind may be *interpretative*. Let me call such an interpretative plan a *schema*. All such schemata are, in technical phrase, " universal " and conceived on this wise—e.g. that of the atom or that of the life of an organism—but each schema is illustrated by particular or individual instances which may be observed in this or that atom or organism. There can be no doubt that adult man—even so-called primitive man—forms practical plans of action and interpretative schemata which, were detailed consideration here permissible, might be distinguished broadly as mythological and naturalistic.

But what can be said about a boy of, say, three years? Has he interpretative schemata? This is surely a question to be answered on the best available evidence. He may or he may not. It is not easy to say. I am doubtful. But I think there is good evidence that practical plans in mind of an eminently serviceable kind have taken and are taking form at this age on the basis of his prior experience in dealing with like situations. There seem to be animals that do not get beyond this stage of mental development. Professor Yerkes, as the outcome of careful observation and cautious inference, says that the orang-utan Julius was not above the level of the normal three-year-old child.

Let us turn aside for a moment to Julius. He has to bring and stack boxes so as to reach a tempting bit of banana. It took him six or seven weeks to hit on the right placing or stacking of the boxes. Then one day " he suddenly seized the smaller box by two corners with his hands and by one edge with his teeth, and after a few attempts placed it on top of the larger box, climbed up and obtained the banana ". On the next occasion, two days later, " he wasted no time, but piled the smaller box on top of the larger one immediately, and obtained his reward. As soon as opportunity was offered, he repeated the performance. The same thing happened on the next day and on several succeeding days. Julius had got the idea."[1] Here there seemed to emerge a practical plan of action, anticipatory to consistent performance in act, repeated as often as occasion arose.

Such plans are sometimes said to be reached by stepping-stones of so-called " trial and error ". This expression is ambiguous. It may mean trying this, that, and the other mode of behaviour in accordance with a plan in mind within which these acts are recognized alternatives. Intelligent folk solve problems on this wise. But it may mean a kind of random " behaviour-guessing " along lines opened up by all sorts of varied habits of action. In the case of Julius the behaviour

[1] *The Mental Life of Monkeys and Apes*: Behaviour Monographs, Vol. III, 1916, p. 96.

during six or seven weeks seems to have been of the latter kind. There was apparently no *de facto* plan of action until the plan in mind suddenly emerged after much relatively aimless unplanned endeavour to get the banana. A vague wish was there, as appetite with prospective reference; probably some foretaste in enjoyment was there as his mouth perhaps watered for the fruit; endeavour was there in the form of varied output of behaviour in modes begotten of the habits so far established; but the *how* of endeavour directed to an end in view comes when, and not until, the plan in mind comes. Thereon follows the translation of plan in mind into repeated and appropriate action. And it seems to come with a jump; it is characteristically emergent. If we try to keep the nose of observation (it requires, of course, some years of training) up against the facts of behaviour in animal or child, and if we refrain from interpreting in terms appropriate to adult human life (and this no doubt is hard), we seem justified in distinguishing (1) planless endeavour to satisfy some insistent " wish ", from (2) planful endeavour when the appropriate " idea " has at last emerged. Then the " unmethodical method " of random hit or miss swiftly disappears from the evidence.

So much—little as it is—in respect of the stage of mental development at which plans in mind emerge in the story as told by the psychologist. The question arises whether in the absence of plans in mind—of course on the part of the living being concerned—the word " purpose " should be used. Does what we commonly speak of as habit necessarily imply purpose in the sense of a plan in mind of which that habit is the expression?

We passed from the adult to the child three years old, and branched off to Julius the orang-utan. What can we say of the child at the close of the first four months of its life? We may surely put interpretative schemata out of court. Are practical plans in mind, anticipatory of acts to be performed, in evidence or not? It is very difficult to say—so much turns on the reading of the evidence. Some years ago (1900) some of the evidence was presented with admirable lucidity by Miss Millicent Shinn

in *The Biography of a Baby*. It seems to be clear from this and later evidence that from the first week onwards there is in course of development *prospective reference* to that which will bring pleasurable enjoyment (or the reverse) and to coming events which, however vaguely, are expected to happen, apparently always on the basis of what has already happened in life-routine. But to produce evidence of the *absence* of plans in mind on the part of the infant is obviously impossible. All that one can say is that evidence of their *presence* is not such as to carry conviction, leaving it for others to give a clear statement of the grounds on which—as a strait question of evidence—they justify their contention that it does carry conviction.

Take now one more step backward in the life-history of the human being, say to the close of the fourth month of embryonic development. Is there evidence in support of the presence of an interpretative schema in the embryo mind? Is there evidence of a practical plan of action as a guide to the further course of embryonic development? If we judge that the evidence in support of one or the other is wholly inconclusive, the question still remains: Is there evidence of prospective reference to events that are coming—let us say only just coming—but have not yet come? Many of us think that no such evidence as carries conviction has been adduced. This does not necessarily preclude the presence of primary reference which is *not* prospective. Of the presence or absence of this, or of some primitive form of enjoyment, we have no evidence. Acceptance or rejection is based on wholly speculative grounds. Most biologists reject such speculative notions, on the principle perhaps: *De non apparentibus et non existentibus eadem est ratio.*

We have now in tentative form an interpretative schema professedly founded on empirical evidence in the light of observation and such inference as we judge to be justifiable. We have:

d. The human adult with interpretative schemata.
c. The child of, say, three with practical plans in mind.

b. The infant of, say, four months with prospective reference in mind.

a. The four-months embryo with no such prospective reference.

In comparative psychology such questions as these arise: (1) Are there animals other than men that reach the top-level *d*? (2) What animals reach the underlying level marked *c*? (3) Do some animals reach only the *b*-level? (4) Are there organisms, plants for example, which do not get beyond the lowest platform of *a*? To these may be added: (5) Is there, say in man, in the course of individual life, such a progressive advance through stages or steps (emergent as I call them) *a*, *b*, *c*, *d*? (6) Do these steps recapitulate stages of evolutionary advance? (7) Are there, even in adult human life, psychological processes going on concurrently and in substantial unity *at all these levels*?

The psychological schema I have given in outline is obviously quite different from Dr. Russell's hormic schema. I do not propose to compare them. That may be left to the reader. I am not sure how far Dr. Russell would claim that there is always something of the nature of a practical plan in mind or perhaps an interpretative schema—for he speaks of the amœba as " interpreting " the stimulation received in accordance with its meaning or significance. I am concerned only to emphasize my belief that, let us say in embryonic development, or in normal plant growth, there is no evidence of even that prospective reference which characterizes the level I marked *b*.

It may be said that no claim is advanced that there is in the mind of the animal embryo or the acorn the completed outcome of development as an end in view—only the next step in such development. The question I raise is this: On what evidence is *any* prospective reference attributed to the mind of the embryo or that of the acorn? Let there be such a series of steps as *m*, *n*, *o*, *p* repeated in the several individuals along some affiliated line of advance. Then, as I understand, the contention is that at any given stage, say *n*, there is at least prospective

reference to the next stage *o*; and that this implies storage in " memory " of what followed *n* in foregoing members of the line of affiliation. It may be so. But until there is cogent evidence that it is so, some of us feel bound to accept a different interpretation.

The Twofold Story in Anthropology

I have now given in admittedly tentative form a psychological schema. But at an earlier stage of this chapter I suggested that in the study of life there are always two stories, or, if it be preferred, there is always a twofold interpretation of the events which are given in any descriptive biography or any episode therein. It may be asked then: Where, in connection with the psychological schema, does the biological story come in? It comes in *all along the line from first to last* as accompanying—not causing or being caused by—the psychological story. Under twofold interpretation, in the one regard we deal comprehensively with the whole evolutionary story from *a* to *d* in terms of mental reference; in the other or biological regard we deal with the whole story, say from α to δ, in terms of physical and physiological influence. But at level *a* (or α)—that is, before there is any *prospective* reference—there is as yet nothing to differentiate the two stories. Reference is there *ex hypothesi*; for if there were no reference, from what could prospective reference be evolved? But until it *does* become prospective, it plays no part in evolutionary advance. Reference, then, counts for progress when, and not until, it in some measure anticipates future events. Hence, as a factor in evolutionary progress, prospective reference affords a new starting-point, and we may say that at this critical point the subject-matter of psychology as an independent province of inquiry has its genesis. If, therefore, we so define " purpose " as to ear-mark some reference to the future as its distinguishing and differentiating criterion, the subject-matter proper to psychology is that in which there is evidence of purpose.

On these terms psychology proper, as a province of inquiry distinguishable, but nowise separable, from biology, tells the

story of purpose, just dawning above the evolutionary horizon at level *b* and reaching its zenith in human folk at top-level *d*. But if we seek to know more about the levels β, γ, and δ, which accompany *b*, *c*, and *d*, I take it that, so far as human folk, mammals, birds, and lower vertebrates are concerned, the chief stress falls on the integrative action of the nervous system, and in lower forms of life on such integrative action as may be disclosed under detailed inquiry.

We are only feeling our way, step by step, towards an adequate two-fold interpretation, subject to the acceptance of an evolutionary schema. I suppose no one is prepared to assert that we know in intimate detail the exact cerebral correlates of plans in mind. But we seem to have good grounds for believing (1) that the psychological evidence of plans in mind runs parallel with evidence (in mammals) of the development of the frontal or pre-frontal regions of the cortex, of course in alliance with the concurrent development of other regions; and (2) that injury to or (under experimental conditions) destruction of this area of the brain is accompanied by grave disturbance (or abolition) of plans in mind.

I cannot here enter into such intricate matters. For a brief account of a naturalistic treatment of the connection of "Brain and Intelligence" the reader may turn to Dr. Bernard Hollander's Presidential Address to the Ethological Society.[1] My present aim is to emphasize the two-story point of view. Take, for example, inquiries in the field of anthropology. Here we are mainly concerned with biography—or biographies interrelated in history—psychologically interpreted at levels *c* and *d*. But such an anthropologist as Professor Elliot Smith seeks to go further. He asks, in effect, how man has been evolved from some ancestor or ancestors not yet human. He helps us to piece together a story of mammalian progress along our line of descent; he bids us take note of the earlier dominance of the sense of smell and the later dominance of that of sight. This implies mental reference to what we speak of as objects in the external world, and it falls within the province of the psycho-

[1] Cf. its *Journal*, October, 1923.

logist. It may then be shown how, as a matter of probable history, the higher senses, as we call them—those of hearing and sight with special stress on binocular vision—widen the field of reference and quicken behaviour in relation thereto within the context of a freer arboreal life; how reference to coming events, expected or anticipated, and consistent endeavour to attain wider ends, become more and more marked; and so on, until, in us, social life with fuller and richer community of reference is reached. All of this is one story told in terms of conscious reference—a story that is distinctively psychological.

But there is the other story which is no less distinctively biological. Correlative to reference to external objects under smell, hearing, or vision, is physical influence reaching the organism from beyond its confines. Correlative to adaptive behaviour under reference to the end it subserves, is physiological influence which reaches the muscles concerned in such action. Correlative to increasing intelligence is increasingly complex provision for nerve-centre integration along lines of nerve-fibrils which transmit special modes of influence under differential " synaptic resistance ". Here in bewildering wealth of detail the story, so far as it can be told, is from first to last one that deals with what Professor Dendy speaks of as a series of responses to stimuli which reach this or that part of the organism from various sources external and internal, all of them subject to the substantial unity of the organism as a whole.

Furthermore, correlative to increasing intelligence and increasing dominance of hearing and binocular vision, are increasing volume, intricacy of structure in, and dominance of, the " neopallium ", with its parietal, temporal, motor, and pre-frontal regions in close inter-relation. Here again one cannot go into detail. But if it be asked on what grounds the necessarily inferential psychological story of widening reference in the mammalia is told, I think Professor Elliot Smith would reply: On the basis of our knowledge of the structure and functions of the brain. In reconstructing the past history of man, evidence other than that afforded by his artifacts and his remains there is none.

In seeking, then, to describe and to interpret, comprehensively and picturesquely, the course of events observed or inferred we may emphasize this story or that—more commonly, perhaps, first this and then that, without pausing to indicate the points of shunting from one line of rails to the other. But because common sense likes to have the two stories commingled, does it follow that a disentangling of the threads of reference from those of influence is not conducive to progress? I submit that much of the work of the anthropologist is distinctively psychological, and here he takes concurrent biological factors for granted. But some of the work is distinctively biological; and here he takes the concurrent psychological factors for granted. What he should realise is that the two stories *are* concurrent and tell of events now in this regard and now in that.

Concomitants of Emotional Enjoyment

In the illustration I have given of the connection of two distinguishable stories the emphasis is on the development of cognitive reference in one story and, in the other, of nerve-centre integration, subject to the principle of the substantial unity of the organism as a whole. But the psychological story includes that which I may perhaps be allowed to speak of as "enjoyment" in a rather technical sense in that it is to include that which is agreeable and that which is disagreeable. Difficult as it may be to conceive enjoyment as separable from cognitive reference, we may none the less distinguish a factor of enjoyment, pleasant or the reverse (i.e. positive or negative) from that of reference to something which, as we say, gives this enjoyment.

I here take emotion as a mode of enjoyment. I believe, on the basis of experience, that it has many emergent qualities. But this is a disputable view, and it need not be brought into discussion. To which of the two stories emotional enjoyment belongs there can be no doubt. One may observe in some other living being its bodily expression; but what I mean by the emotion itself—fear or anger or anxiety—can only be felt in the course of experiencing on the part of one who experiences.

It is, however, quickly caught up into the field of reference and becomes linked in peculiarly subtle ways with the perception of objects and objective situations. Under fear there arises reference to that which evokes this mode of experiencing. Under anger there is reference to one who provokes this emotion. No less closely linked is the emotional state with some mode of behaviour within the situation. But I seek to distinguish what it feels like to be angry, let us say, from that which is provocative of anger and from what the angry person does.

Emotion, then, falls within the psychological story. But there is also a biological story. There are physiological processes which accompany the emotional enjoyment as such. And we are, I think, too apt to commingle rather distractingly the two stories, and not only to sandwich a bit of the one with bits of the other but to lose sight of the essential feature of the biological story as such. Hence many people suppose that a two-story view necessarily implies the paradoxical inversion of the sequential order of events which William James sought in vain to render comprehensible to common sense. Most of us remember how it ran. We meet a bear, under circumstances which are left to conjecture. Describing the episode we say that we were frightened and that on this followed trembling, catch of breath, palpitation of the heart, and so on. What we ought to say, according to James, is that we trembled (and the rest) and that on this followed the felt emotion of fear.

There is here pretty obviously a commingling of the two stories. When James says that between perception and emotion " the bodily manifestations must be interposed " he inserts a biological link in the midst of a psychological story. But he has said, a few lines above, with the emphasis of italics, " our feeling of these changes as they occur *is* the emotion ".[1] Hence there is no leading or following; there is just concomitance or accompaniment. And on this he lays further stress when he says that a purely disembodied emotion is a nonentity.[2]

[1] *Princ. Psych.*, ii, p. 449. [2] Op. cit., p. 452.

I hold no brief for William James. Indeed his brilliant and picturesque treatment of emotion is not a little bewildering. His purport is to give a genetic account of the probable manner in which this form of concomitance arises at the very outset of emotional experience; and yet most of his illustrations are taken from the level of adult human experience. His task was to show the nature of the correlation which obtains prior to the lessons of experience; whereas the examples he cites are from a stage of human life at which our current experience implies the psychological outcome of much that we have learnt. Hence—according to an oft-quoted criticism—if one meet a bear in the Rockies one may offer him a clean pair of heels or a rifle bullet, as the case may be; but if one see him in his den at the Zoo one may offer him a bun.

From the biological point of view we have to inquire: What is the specific form of excitation or internal stimulation which so influences certain deep-seated organs as to give rise to those changes which are the bodily accompaniments of what, as emotional experience, has place as enjoyment within the psychological story as such? James realized this; and much of his discussion is still of value. But new light has been shed on the whole matter since his day. For it seems that the manner in which the internal organs respond under some exciting nerve-influence in large measure depends on the bio-chemical influence of the internal secretions of "endocrine" glands (containing "hormones") which are conveyed to the responding organs by the blood-stream. Excess or deficiency of the bio-chemical products of the thyroid or the adrenal glands may profoundly modify the biological story; and there is concomitant modification of the story of emotional enjoyment.

This further illustration of the connection of the two distinguishable stories serves, therefore, to show that we have to reckon with a kind of physiological integration—through distribution of bio-chemical products—that is supplementary to nerve-centre integration, and that is closely correlated with psychological integration in enjoyment.

An Approach to Heredity

There can be little doubt that, whether we may speak of it as emergent or not, a distinguishing feature of the subject-matter of biological inquiry—in the broad sense that includes a psychological story—is hereditary transmission in some sense of these words. Hence organic evolution embodies a doctrine of descent where " descent " implies a kind of handing on from parent to offspring which does not occur on this wise in entities of abiological status. And I take it that what has here for most people chief interest is the vexed question of the inheritance of acquired characters. Probably for them this interest centres chiefly on the inheritance of mental characters. What they want to know is whether the biological evidence is such as to justify the common belief that what the parents learn in the course of their individual experience is in some way transmitted to their children, and, if so, how.

As an approach to this problem let us consider the report that Professor Pavlov has recently given of the results of an interesting inquiry. I will tell the story first in terms of psychological import under reference. While some white mice under observation were feeding, an electric bell was rung. After a time an association was established and the mice showed signs of expecting food on sound of the bell, though no food was there to stimulate the organs of vision or smell. So far the mice differed little in their mode of behaviour from one's dog Fido who runs in from the garden when he hears the luncheon-gong. But the recent observations on mice disclose a new feature. It took them quite a long time to learn that the sounding of the bell means food. Some 300 lessons were required. But for the children of these mice 100 lessons sufficed; with their children only 30 lessons were needed; and in the case of their children, in the third filial generation, but 5. Have we here the inheritance of " an acquired character "?

We certainly have evidence of a response to the bell that is more rapidly " acquired " in succeeding filial generations. In other words the habit of responding to this call to meals

is much more readily established in the great-grandchildren. But it still required five lessons. In observations of my own on young birds a habit of avoiding such nauseous insects as soldier-beetles was established on a basis of only one or two lessons. And yet in thousands ot experiments I have never observed avoidance at first sight, that is without any learning.

If, then, we say (1) that an acquired habit is " inherited " when *no* individual learning is needed, Professor Pavlov's experiments afford, as yet, no evidence that the sound of the bell means food prior to *any* lessons. But if we say (2) that such a response is " inherited " when the requisite lessons are reduced, say from 300 to 5, then obviously the evidence for the " inheritance of an acquired character " is conclusive. It may seem that the distinction here drawn between (1) and (2) savours of hair-splitting. But surely there *is* a difference between learning more easily and not having to learn at all.

A further distinction needs emphasis. I have spoken of habit and of learning. What then is a habit? May one say that it is a mode of response that is acquired in the course of individual life? That will include habit in both bodily and mental regard. But in the psychological story we say that a habit is acquired in the sense that it is learnt. Learning, however, in psychological regard, may be at the level I marked *c* or at that of *b* (*not* that of *a*). In either case there is some prospective reference. At level *c*, where plans in mind are in evidence, there is learning for the sake of some end in view mentally envisaged prior to action. But did Professor Pavlov's mice thus learn? Of course on hormic principles they did; for on these principles there is always an end in view however ill-defined. Some of us, however, think it more probable that the end in view was in the experimenter's mind and not in that of the white mouse. They " learnt ", as I surmise, much as a young chick " learns " to avoid nauseous insects. Learning in this sense implies no more than the establishment of an associative connection between " this " and " that " which is retained in such wise that on subsequent occasions " this " is revived on the recurrence of " that ". It is questionable whether in

the white mice there is more than such associative revival.

So far we have kept to the psychological story. Here there seem to be good grounds for inferring expectation, with prospective reference to what will come under routine imposed by the observer. Turning now to the biological story we may take the accompanying psychological story for granted. We want the biologist, on his part, to tell us what physiological events presumably run their course in the mouse—I say " presumably ", because the story has to be pieced together from bits of evidence afforded by many investigations on the integrative action of the central nervous system. It is, I think, the story of what Professor Pavlov himself has taught us to call the " conditioned response ".

It is a terribly complex matter and demands some knowlege of the nature of " neurone routes " in the brain. Reduced to its simplest terms, in diagrammatic form, something of this sort seems to go on in the mouse-brain. Prior to the experiments there seems to be a " primary response ", eating, to appropriate food-stimulation. And these—stimulation and response—are connected by a " primary brain-route " from one to the other. Let us call it the " feeding-route ", and label it F.R. Thus far, then, we have:

(1) Food-stimulation → F.R. → eating.

There seems also to be another, and initially unconnected, " primary response ", namely pricking of the ears to auditory stimulation, say from the bell. And these are connected by their " primary brain-route ". Let us call it the " ear-route " to the muscles concerned in the pricking of the ears, and label it E.R. Then on this count we have:

(2) Auditory stimulation → E.R. → pricking of the ears.

Let us assume that (1) and (2) are " inherited " as initially " permeable " brain-routes, as seems to be the case. But under " inheritance " the brain-route between F.R. and E.R. (for which there is structural provision) seems to be relatively

" impermeable "—in other words it has to be " acquired " as an open route.

But let (1) and (2) occur, under experimental conditions, concurrently, so many times as the evidence may disclose. Then, and not till then, they seem to be connected by a " secondary brain-route " of " acquired permeability ". When this acquired brain-route is established there is no longer any need for food-stimulation from food actually in view or within scent-range, still less as affording touch or taste. Then we have:

$$
\begin{array}{lrcl}
 & & \text{F.R.} & \rightarrow \text{eating.} \\
(3) & & \uparrow & \\
 & \text{Auditory stimulation} \rightarrow & \text{E.R.} &
\end{array}
$$

The " nerve-waves " are switched off at shunting points in the brain from the ear-route to the feeding-route.

Here the pricking of the ears may no longer be observably " expressed ". It is probably " suppressed " (under inhibition) to the level of a slight twitching of the ear-muscles. And even the eating of the food may not be fully carried out. At first it may get no farther than some incipient twitching of the muscles concerned in mastication, some incipient effects on the organs of digestion. Probably (on the basis of Professor Pavlov's work on the dog) there is some more than incipient flow of saliva. The mouth may water for food to come in due course.

Here the biologist asks the psychologist: May not this partially suppressed and not yet fully expressed prelude to the actual eating afford the physiological correlates of what in your story is expectation? May not what is for me *present* physiological influence afford a clue to the genesis of that *prospective* reference on which you lay so much stress? The influence is here and now; but the reference, under revival, is to events which will come in normal routine.

I have put the matter as briefly as possible—in my own way, subject of course to correction by experts. At this *b* level of development the position to which inquiries psychological and biological seem step by step to be working up is that what in the former story we speak of as gaining experience in the

course of individual life is, in the latter story, the establishment of an extraordinarily complex system of conditioned responses.

I am loth to introduce added complexity. But the complexity is there, and it must not be shirked. We saw that part of the response to food-stimulation is the action of the salivary glands. When such glands, and generally speaking any internal organs, are called into action, they give rise to an internal receptor-pattern of excitation analogous to the external patterns of stimulation, visual, auditory, and so forth. The one kind of pattern is the biological correlate of what is experienced as happening in the body, with or without mental reference thereto; the other kind of pattern is the correlate due to what is experienced as happening in the outer world to which there is the mental reference commonly spoken of as objective.

We have, then, to link up what I have said in respect of the conditioned response, with what I said above with regard to emotion. The felt emotion of fear has as its bodily correlate some kind of organic commotion inside the organism, let us say among other things palpitation of the heart. Now one very common form of stimulation to such responsive behaviour as is apparently accompanied by fear, is a sudden sound-shock. It is easy so to arrange matters on the lines of Professor Pavlov's experiments on mice, that, when an animal or child sees some object, a sound-shock or an electric shock is given which elicits the fear-response. After a few experiments the shock is no longer required. The animal shows the conditioned fear-response at sight of a like object. The already complex business of conditioning is thus rendered still more complex when we introduce this new set of brain-routes, having their starting-points of excitation within the depths of the organism as a "going concern" but debouching on the organs of response by what Sir Charles Sherrington has taught us to recognize as final and common paths.

But we saw that emotion in the psychological story is closely allied with the action of the endocrine glands in the biological story. When a cat is violently excited by a dog, and presumably experiences fear and perhaps anger, its adrenal glands are called

into strong action. Its bodily system is flooded by an " internal secretion " containing adrenalin. The whole physiological poise is then altered; with it the behaviour of the animal. So far as we can judge the whole mental poise exhibits an accompanying change. And if the adrenalin be injected into the blood of another cat the whole physiological poise—and seemingly the mental poise—of *this* animal is altered in a similar manner. What evidence is there of such biological change of poise? Dr. W. B. Cannon tells us that there is increased liberation of sugar from the liver, and the presence of this sugar in the blood-stream enhances muscular action. There is withdrawal of blood from the abdominal viscera, and an augmented supply to the heart, lungs, central nervous system, and muscles concerned in behaviour which are rendered less fatigueable; and so on. I am well aware that Dr. Cannon's finding has been subjected to criticism. My aim is to show the kind of evidence which on due sifting still points to some correlation of emotional enjoyment and endocrine action.

I cannot here enter into further detail. Nor can I attempt to tell the very intricate story, in biological regard, entailed (1) by the twofold conditioning of brain-routes which are, in technical phrase, of " extero-ceptor " and " proprio-ceptor " origin respectively, and (2) by the wide-spread influence of the internal secretions containing hormones.

A Plain Tale and an Interpretative Story

We took Professor Pavlov's mice-observations as an avenue of approach towards the problem of heredity. The outcome of his inquiry was to show that, in the psychological story, associative learning is facilitated in later generations by what is acquired in earlier generations. We then turned to the biological story. And it seemed probable that, in this story, the establishment of secondary brain-routes in conditioned responses is in like manner facilitated. We want to know how this is to be interpreted.

I have proceeded on a two-story hypothesis as that which, in my judgment, best fits the observable or inferable facts. On this hypothesis the inheritance of mental characters in psycho-

logical regard has its correlative counterpart in the inheritance of physiological characters in biological regard. Hence, as Professor Dendy recently said: " It is only in so far as they are related to the brain that the inheritance of mental characters can have any meaning from the biological point of view. . . . There is no *a priori* reason why mental characters, closely correlated as they are with brain-structure, should not be inherited in exactly the same way as bodily characters, and indeed there is abundant evidence that this is the case."

We shall have to consider in due course later on the distinction between that which is *inherited* and that which is so *transmitted* as to afford the basis on which the inheritance of " characters ", bodily or mental, in later life is founded. On hormic principles " memories " are, it is said, transmitted as such. Those who are not hormists contend that though such transmission of memory-images and the like is asserted again and again and yet again, no satisfactory evidence in support of this reiterated assertion has been adduced. Hence the status of memory is one of the main issues on which hormists and non-hormists are in radical opposition.

At any rate when we come to grips with the problem of heredity *in biological regard* it must be subject to the concept of physical and physiological influence. We must proceed on the canon of biological interpretation: The entire life of any organism consists of an enchained series of stimuli which reach it, or its constituent parts, from various sources. This is not in accordance with the hormic schema; but, for better or worse, the interpretation I offer is cast on quite other lines. Without prejudice to the *d* level, *c* level, or *b* level of my pyschological schema we are now digging down to the *a* level, where there is as yet no *prospective* reference such as arises in connection with the conditioned response in vertebrates or some analogous process in lower organisms.

There is, then, at the level we now reach no independent psychological story. If reference there be it is not yet prospective; and it is only when mental reference *is* prospective that it begins to count—and thereafter counts more and more—

in life-progress. We may therefore now restrict our attention to the biological story.

I must revert, however, to the distinction between what one may call a plain unvarnished tale (biographical) and an interpretative story. What do I mean by a plain unvarnished tale? I mean that which is frankly and naïvely descriptive only. I mean such a tale as the microscopist gives us in describing the nuclear changes in karyokinesis; such a tale as the embryologist tells of the blastula, the gastrula, and the differentiation of primary or secondary tissues; such a tale as the botanist may tell of the formation of shoot and root and the directions of their growth in a kidney-bean embedded this or that way up; such a tale as may be told, in frankly descriptive terms, of the passing of a cartilage model into a calcified bone; such a tale as Mendel told of his tall and dwarf peas. I may assume that such tales are not unfamiliar to a reader of this chapter. They are, one and all, plain and unvarnished tales in so far as they are just descriptive of a given set of directly observable facts.

But if we say that the facts which the tale discloses may be interpreted in terms of some physical influence such as the " gravitative influence " on the tissues of the bean-plant giving negative geotropism in the shoot and positive geotropism in the root; if, so far as is at present possible, we show the manner in which this influence is translated into what Professor Child calls " metabolic gradients " directive of growth; if we attribute the passage from blastula to gastrula to some external influence or to the mutual influence, bio-chemical or other, of the constituent cells on each other; if we assign to the centrosome some specific influence in the process of karyokinesis; if we trace the influence of the distributed chromosomes on the cells to which they pass; if, in chromosome terms, we seek to account for Mendelian characters as dominant or recessive; then our aim is to interpret a descriptive *tale* as a biological *story* under the guidance of its leading concepts of stimulus and response.

But where does heredity here come in? First, there is, I take it, a plain tale under what is spoken of as hereditary correlation. It is merely descriptive of the facts which are observed,

though the description is generalized, condensed, and formulated in some convenient and helpful way. Secondly, any such tale as has been adduced not only tells of some particular or individual sequence of events but is descriptive of a natural plan of the set of events under consideration. Thus the tale of the kidney-bean is that of any such bean as is normal. But, thirdly, we have to deal with affiliate " lines of descent " having some kind of genetic connection. In the individuals severally developed along any such line of descent there may be instances of an unchanged plan; or there may be descriptive evidence of some change of plan. This persistence of unchanged plan, or this modification of plan, where external conditions of influence may be taken as normal, is the subject-matter of heredity. Interpretation of persistence or modification in terms of stimulus and response is the story which gives biological meaning to the merely descriptive tale.

An hereditary tale—this or that, or comprehensive of all thises and thats—though it may be full of varied incidents, is tolerably straight-forward and not very hard to follow. But a biological story in detailed terms of specific modes of influence is, from first to last, very difficult—perhaps especially so in its opening paragraphs if we start at the beginning of individual life. Not only is one faced by a bewildering wealth of detail in minute compass, but the whole story bristles with technical terms which specialists have coined for usage in discussions among themselves. Of the meaning of some of these the interested outsider has some inkling; for the rest he cherishes hope of further enlightenment.

The most I can do in the space I have left for this branch of my topic is first to deal with some general considerations, and then, without entering into detail which must be sought elsewhere, to indicate one of the lines of inquiry which seems to hold promise of further advance.

Some General Considerations

We see in the living organism a vast number of orderly events in behaviour and in the development of structure and

function. Let us admit—though we must realize that there are many biologists who do not admit it—that, whether subject to what I call emergence or not, there is here a kind of substantial unity that characterizes the going-together, within an organism, of diverse events no less special in kind. In other words there is here something different from anything we observe in the inorganic world. No doubt a great number of these events are of the chemical order. But they run their course under conditions which seem to obtain only in the living organism. Hence they are spoken of as bio-chemical, which means, for us, that they are not chemical *only* but are *also* physiological or metabolic. That is what I seek to emphasize by speaking of them as emergent as contrasted with resultant. But what in more concrete terms are we to understand by this? What kind of events seem to be distinctively biological? One can only indicate what seems to be salient in our present context. Without prejudice to the physico-chemical processes which are involved, and as I believe always involved, such characteristic biological processes as cell-division and cell-differentiation, as chromosome-partition and distribution, as the reappearance in offspring of characters like those in the parent or parents; these seem to be quite distinctive of living beings and are part of the subject-matter of biological inquiry. But these fall within the purview of heredity.

In the organism, then, events proceed on their course in a distinctive manner elsewhere unknown; and these events exemplify some plan of life-routine which the biologist seeks, not only to describe as accurately as he can, but to interpret so far as the present state of our knowledge permits. The observed routine is, however, not invariable; for (1) no two organisms are quite alike, and (2) in no two organisms are all the conditions, external and internal, quite the same. We proceed, therefore, on the hypothesis—justified, as we think, by the results of observation and experiment—which may be thus formulated: If the sequence of external stimuli and internal excitations be altered at any given stage in a degree to be determined by careful inquiry, the course of events will be

altered in such wise as observation discloses. In other words: On this hypothesis, from change of plan in life-routine we infer some change of influence external or internal.

Coming now to closer quarters with heredity the question arises: What is inherited? Considered in biological regard the word " inherited ", or rather the concept it embodies, needs scrutiny. We commonly say that this or that mode of behaviour in one of the higher organisms—for example nest-building in birds—is inherited. The biologist may speak of such inherited modes of behaviour as " instinctive "—of course, on the interpretation here in view, without any of the hormic implication recently imported into the connotation of the word " instinct ". Similarly, on a lower plane of life, we may say that flowering in some plants, or the formation of fruit and seed in due course, is hereditary. We know pretty well what we mean in such cases. What, then, do we mean? We mean, I take it, that something which we may provisionally call the capacity of nest-building or flowering, as the case may be, is transmitted from parents to offspring. We thus introduce the concept embodied in the word " transmission ". We say that inherited capacity is transmitted. But the word " capacity ", in a biological context, is scarcely less vague than " potentiality ", or is little more than some specialized potentiality. Cannot we substitute something actual and concrete? Let us try structural provision. Then, in the adult bird, there is structural provision in receptor-organs, nervous-system, motor-organs, and so forth, for nest-building. We say that such structure is inherited. But in what sense is it transmitted?

Of course we may—and in popular speech we do—use the words " inherited " and " transmitted " as synonymous. But we may, and I think we should, differentiate in such wise as to ear-mark " transmission " for the handing on of something which is biologically recognizable, along the whole course of events under consideration. Is organized structure transmitted in this sense? Can the " organization " which provides for nest-building be discovered in the fertilized ovum which we may speak of, metaphorically no doubt, as the " channel " of trans-

mission? Nowadays we think not. So we seem to be thrust back on to an inherited capacity of organizing the structural provision for nest-building—or, indeed, of any "unit-character" in Mendelian parlance. What then in concrete form is transmitted? Not the character itself but some biological provision for its appearance in due course. Shall we say, provisionally, that certain minute structures within the minute structure of the cell-nucleus, as the "bearers of heredity", are actually transmitted through the fertilized egg and thereafter distributed, here, there, and elsewhere, among the daughter-cells which build up the bird that builds a nest? Thus we pass to the very fruitful field of Mendelian interpretation in terms of factors or genes and so forth.

Even so, however, the question arises: How comes it that they or their products are so distributed? No doubt, could we only trace it, there is along each line of distribution an enchained sequence of "stimuli and responses" following or marking the course of what Professor Child would call a "metabolic gradient". Yes. But it may still be asked: How comes so wonderfully orderly a distribution according to the plan of organization in this or that living being? Can we say? Are we not once more thrown back on to something of the nature of an organizing capacity in the developing embryo? If so, to call it the mind of the embryo does not help us a whit *biologically*. It seems that we must just accept the plans of natural events—these plans and others—as we find them.

Parenthetically I may here say that from the point of view of emergent evolution the organizing capacity of the organism—let us speak of it as synthetic—is analogous to the synthetic capacity in atom-building, molecule-building, or crystal-building, though of course it has the distinctive emergent character appropriate to the level of life and elsewhere unknown.

I may here ask one more question based on general considerations—not with respect to observable fact in a descriptive tale, and not with respect to the Mendelian story interpretative of the tale, but merely with respect to the application of the word "inheritance". Let me take a concrete example. The

Jungle Fowl has the characteristic " single comb ", which is seen in many domesticated breeds. But other modern breeds have the knobby " rose comb "; others the " pea comb " or the " walnut ". Professor Bateson has obtained striking results by crossing the breeds and has ably discussed them in Mendelian terms. I put my question in hypothetical form. If the original comb was "single"; if "rose", "pea", and "walnut" appeared at some stage of the history of domestic fowls as genuinely new; should we, or should we not, speak of these new characters as inherited? If we do so, then in what sense, since in the plain tale they were present in the offspring but absent in the parents and ancestors? If not, it seems that, in the plain tale, these new characters sprang into being independently of inheritance. I do not suggest any doubt that an interpretation of the plain tale must be sought in terms of Mendelian factors under concepts embodied in the words "dominant" and " recessive ". I only ask whether the intricate interplay of the factors gives *resultant* effects only. Some of the effects seem to be quite distinctively *emergent*—giving genuinely new characters. One does not deny much " blending " which is susceptible of resultant interpretation; one does not ignore such " mosaic combination " as is well illustrated in some species of ants; but one does ask whether the really new is inherited, and if so, in what sense. Since this turns on the exact connotation of " really new " and of " inherited ", it is a matter which falls under " general considerations ".

Towards a Bio-chemical Schema

We commonly think of " factors " in terms of prospective reference to the characters which will be their outcome in due course of natural routine. But a biological interpretation is in terms of present influence at any given stage, not of prospective reference. We ask: What here and now is the response, of such and such a kind, to external stimulation or internal excitation, of this kind or that? Of course in many cases we do not yet know; but that is what we seek to learn.

Let us return to the vexed question of the inheritance of

acquired characters. We considered the results of Professor Pavlov's experiments on white mice. If, as I suggested, we have here a conditioned response, the biologist may be asked to tell us (1) under what current modes of influence, in physiological regard, secondary routes in the brain are established; (2) in what manner they become what one may call preferential routes on subsequent occasions in individual life; and (3) how the constitution of the individual is so modified, bio-chemically or otherwise, as to facilitate conditioning in successive filial generations. If it shall some day be shown that "secondary routes", established in the course of individual life, are inherited as "primary routes" which need no such conditioning, this will open up a further problem.

Now this is a highly specialized example, involving a well-developed nervous system of the "synaptic" order, as contrasted with a far more primitive "nerve-net". If we dig deeper down to biological foundations I think one may say that the outcome of recent discussion tends to show that no sharp distinction, still less any separation, of "acquired" from "inherited" can any longer be maintained in the sense that seems obvious enough when such highly specialized cases only are under consideration.

This may seem an exaggerated statement seeing that Weismann regarded the distinction as deeply embedded in the very foundations of biology.

Under his dominance, now on the wane, it was held that, broadly speaking, the germinal cells are strung along a rather isolated line of advance. The germ-cell is the mother of all the daughter-cells of the organism; and most of these constitute the bodily or somatic tissues. Some daughter-cells, however, are other germ-cells, and it is they who hand on the hereditary characters. They are not only daughter-cells but, under suitable conditions, the mother-cells of organisms. The somatic daughter-cells are not in the same sense mother-cells—the potential mothers of what we call offspring. There is therefore *ex hypothesi* no inheritance from body to germ. Inheritance, properly so called, runs always the other way—from germ to

body. But by what has been called a sort of pseudo-inheritance, in syphilis for example or in alcoholism, the germ may be infected in such wise that the children suffer ill effects more or less like those which their parents acquired. But why, one may ask, should these be regarded as other than true cases of inheritance? Is it unjust to say that a not-uncommon reply was in effect: Because this is not in accordance with our theory that all true inheritance runs from germ to soma?

Be that as it may, further inquiry seems to show (1) that a rigid distinction between blastogenic characters of germinal origin and somatogenic characters due to acquired modifications of bodily organs, or their manner of functional action, tends more and more to break down; and (2) that so-called infection of the germ may afford the leading clue to the right understanding of inheritance in terms of stimulus and response.

It seems increasingly clear that, supplementary to the "hormones" and analogous bio-chemical products of specialized "endocrine glands", there are products of metabolism such as those which go by the general designation of "antibodies". They are, so to speak, bio-chemical antagonists to the "bodies" or their products. According to the careful work of Messrs. Guyer and Smith, if a preparation of serum containing a decoction of the lens of the eye be injected into a rabbit, a specific antibody-product is abundantly formed. This antagonizes the effects of the lens-bearing serum. But it seems also to pass into the fœtus in the mother's womb, and antagonizes normal lens-formation in the embryonic eye. Hence this eye has a defective lens. And the defects thus produced may be, perhaps cumulatively, inherited for many generations. We must await the results of further inquiry along such lines as this.

Meanwhile, if only as a guide to yet further inquiry, we may widen and deepen the range of a bio-chemical schema, as an hypothesis to be tried out on its merits, and, of course, without prejudice to other co-operant factors. It seems probable that not only the specialized endocrine glands, not only certain constituent parts of glands with other functions, but every cell

of the body and every chromosome and chondriosome factor is, whatever else it may be, a centre of bio-chemical influence to which other cells and other chromosomes respond in their mode of action. Throughout the organism there is give and take. There seems to be ample provision for the transference and distribution of chromosomes and probably of chondriosomes. There is also, we may believe, a transfusion of their bio-chemical products. Hence every living cell is, so to speak, steeped in a " bio-chemical brew " of bewildering complexity. How it responds depends on how it is embrewed. The brew is ever changing in subtle ways and contributes to the physiological poise of the time-being. And the germinal cells, no less than the somatic cells, are steeped in this bio-chemical brew.

Now if we take seriously the biological canon of interpretation that the entire life of any organism consists of a series of responses to stimuli which reach it from various sources; if we regard it as applicable not only to the organism as a whole but to every organ, tissue, and constituent cell; if without prejudice to other co-operant factors we may emphasize bio-chemical stimulation; then we may say: (1) No response without adequate stimulus; (2) Every response strictly then and there; (3) Then and there always in the course of individual life. On these terms, and in the sense intended, is any response other than acquired, or, if it be preferred, re-acquired in each filial generation, though not necessarily under quite the same conditions of stimulation? If so, does the distinction between the acquired in one generation and the re-acquired in the next betoken a cardinal difference in principle?

Next as to hereditary transmission. Stimulation and response always occur at some given here and now, no matter how great may be the distance of the source from which the stimulating influence comes. When the retina is stimulated, light waves are physically transmitted from some star, let us say, very distant; and when sugar-production is enhanced in the excited cat, adrenalin may be said to be transmitted to the liver. But this is not what we mean by hereditary transmission. What then do we mean?

Let us realize that under the concept of stimulus and response within the body there is implied some differentiation of that which stimulates and that which responds. It may be the differentiation of two organs or two cells by one of which the other is bio-chemically influenced; or it may be the differentiation, within the confines of the cell, of, let us say, cell-body and chromosomes with such influence, reciprocal or other, as minute inquiry may disclose. In what sense, then, is there hereditary transmission with respect to either cell-body or chromosome? Is there aught else than subdivision or partition in the one and in the other? There may be equi-partition or unequi-partition, but in either case it is just subdivision of that stuff and substance which is not strictly speaking " handed on " but *continuously abides*. No doubt there may be handing on or transference of some part of this cell to that cell, as in fertilization. And we may, under suitable definition, speak of such transference of stuff and substance as hereditary transmission. But when we dig down to biological bed-rock, and try to think consistently in terms of stimulus and response, we seem to be restricted to present action with partition, in varied ways, of stuff and substance that persists or abides, and transference, in varied ways, of portions or products of this stuff and substance from one cell to another. An inherited character in later life, similar in parent or offspring, is the like outcome of a long and complex series of responses to a relatively constant constellation of stimuli.

Concepts of Evolution

I have sought to show what, in my judgment, is the place of biological inquiry in the comprehensive schema of that which I have ventured to call emergent evolution. Under this schema, when we reach, in the course of natural advance, the level of life, there tall two interpretative stories—both biological in the broad sense, but, in a restricted sense, the one biological, to be told in terms of present influence, the other psychological, to be told in terms of mental reference. This latter story affords an independent province of inquiry when,

and not until, the reference is prospective to coming events, expected because like events have already come in the course of normal routine.

Since the word " evolution " is now used in very different senses with wide divergence of implication, it is incumbent on those who do use it, with or without some qualifying adjective, to state as clearly as possible what *they*, on their part, mean by it. This I have tried to render comprehensible with respect to emergent evolution. The concept is applicable to all such natural entities, inorganic and organic, as severally disclose substantial unity. It concentrates attention on ascending advance towards increasing multiplicity and complexity in items of constituent stuff and increasing richness in substance. The regressive process, no less common throughout nature, is dissolution, where the ascending course of evolutionary advance in integration is, broadly speaking, retraced in descending disintegration. Genuinely new characters emerge along the line of advance; old characters reappear along the line of regression. But in any highly complex natural entity, and conspicuously in the living organism, both processes occur, the one among these, the other among those, of the constituent items of its stuff. Ascending " anabolism " here, descending " katabolism " there, conspire to give the total " metabolic poise " which marks the substantial unity of the organism in its entirety. Such in brief is my concept of emergent evolution.

There are, however, many who, in broader usage, speak of the evolution of scenery, the evolution of the volcanic district in the Auvergne, and so on. It is clear that the word " evolution " is not here used in the emergent sense. Even when we speak of the evolution of the solar system the word is not so used; for though we are dealing with a natural system, there do not emerge genuinely new characters, at definite stages of advance, which distinguish the system as a whole. The sequence of events is interpretable in resultant terms appropriate to " celestial mechanics ". This broader use of the word connotes, I take it, natural genesis.

On the other hand there are those who contend that the

word " evolution " is properly, that is, in their usage, applicable only to vital phenomena. Among these some distinguish racial evolution from individual development. The racial and the individual are, however, closely connected in so far as the story of the latter is a recapitulation, with suitable omissions and abridgement, of the story of the former. Thus evolution—which here implies the adjectival qualification " organic "—means, on this showing, a " doctrine of descent ".

But a " doctrine of descent " may, or may not, be combined with the more speculative doctrine that vital phenomena should be explained in terms of hormic concepts. For those who contend that such a combination is essential, evolution carries this philosophical implication. It deals not only with that which is evolved but with Life or Mind as the Élan or Urge of which the evolved is merely the phenomenal expression.

This supplementary philosophical concept may, or may not, be accepted as necessary or indeed valid for the interpretation of " vital phenomena ". For Darwin evolution meant a *de facto* " doctrine of descent " with emphasis on natural selection. A hormic explanation was, as I judge, quite foreign to his thoughts. And though we now hear much of a revolt from Darwin, his cardinal contentions for an enfiliated descent of all organisms and for a progressive elimination of those which are ill-adapted to the conditions of their life, are still widely accepted, in whatever degree his views of the origin of favourable variations and of the origin of species may need modification in ways some of which he would probably have welcomed under that breadth of outlook to which few of his successors have attained.

For Lamarck, on the other hand, what we call evolution meant a doctrine of descent subject always to hormic explanation. His stress is on needs to be satisfied through endeavour which is the parent of habit. Inheritance of structure begotten of habit is contributory but incidental. That which is essential is transmission of the stored memories which habits imply. And such transmission of memories is hormic to the core.

Evolution in this hormic sense retains the older implication

of the word. It is a process in time through which there is progressive unfolding, as explicit, of that which was already implicitly in being. It is thus contrasted with the epigenetic coming into being of that which is genuinely new.[1] But, in each case, emphasis is laid on the temporal nature of the process. According to the hormic schema development is always a disclosure of purpose present in the mind of this or that living being with teleological reference to a succeeding phase not yet in being. Many of those who attribute, as I do, the whole sweep of evolutionary advance to Spiritual Agency conceive the Divine Purpose, thus manifested, as itself timeless and omnipresent, and therefore not susceptible of treatment in temporal or spatial terms.

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[1] Cf. James Ward, *Realm of Ends*, pp. 97 ff.

CHAPTER V

Botany

Professor Watts has remarked in a recent address[1] that "the essence of evolution is unbroken sequence". On the positive side that statement involves the old dictum *omne vivum e vivo*: negatively it connotes that we possess no sufficient evidence of spontaneous generation. On our present experience we see that life always springs from life, and that it does not arise *de novo* from non-living matter. It may be a question whether that was always so, or how long it has been so. On this point actual evidence is wanting, and there is no need to indulge in mere speculation. For all practical purposes the principle of unbroken sequence may be accepted as the foundation of our present theoretical position. If the necessary data were available, then it should be possible to trace back each of the diverse evolutionary lines represented by life now existent upon the earth to its source. But it is quite gratuitous to assume that all life sprang from a single source.

Early post-Darwinian systematists optimistically thought that by using the data already at hand it might be possible to construct a natural system that would truly represent evolutionary lines, connected so as to form a "genealogical tree". There is at the present time a marked reversion from that hopeful attitude. Many doubt whether, for the kingdom of plants at least, there ever was a single trunk, or common source for all. Others assert more definitely that there was not, and that such evolutionary lines as comparative morphology may

[1] British Association, Toronto, 1924.

trace must always vanish downwards, as they do to-day, in uncharted mist: but it is undeniable that their characters do in a measure converge before they finally disappear in unattached or " blind " ends. Such opinions betray in varying degree a negative attitude as to the lines of descent. On the other hand, a more speculative method has lately been adopted as applied to plants. For instance it permits of comparison between the form of certain of the higher algæ and that of primitive land-plants, and especially of certain early fossils. This is held to indicate the origin of a land-flora from certain higher algal types. Such speculations point in the direction of a more positive attitude as to descent in the plant-kingdom. With these divergent opinions before him, what should be the course of a comparative morphologist who aims at ultimate truth, and is unwilling to sacrifice scientific method for the advantage of arriving at some facile conclusion that may in the end prove to be false?

Methods of Inquiry

Clearly he will be wise to fall back upon strict methods of inquiry, and will examine those methods critically. He will scrutinize the data on which his comparisons are founded, and observe a just balance in estimating their relative importance for purposes of argument. He will gather cognate data from forms living and fossil which are manifestly akin, and will widen to the utmost the criteria of his comparisons. He will co-ordinate the results, and will draw his conclusions only so far as the actual facts will justify. In general he will prefer inductive reasoning from the facts observed to any form of deductive argument.

But it will be objected that if so rigid a course be pursued the student of evolution will not get far. Most of the larger groups will be " left in the air ". That is true enough. Perhaps we shall get no farther than arranging the living representatives in such sequences as are in accord with the fragmentary fossil record, and there we should be content to stop till better knowledge comes. But in the doing of this there will sometimes

emerge that better knowledge, and with it a clearer vision. The first question will then be as to the several lines of inquiry that may be applied to the evolutionary problem for plants.

Lines of Inquiry

I. The most obvious, as it was also the first in the history of botanical science, is comparison of the *external form* of the adult. External morphology was indeed the basis of all early classification, and it still takes its full share in comparative study. But in itself it is essentially a superficial basis for far-reaching conclusions, and this is shown by the fact that in ferns, as also in flowering plants, the mere outline of the leaf may be so alike in plants of distinct affinity that conclusions drawn from it have to be constantly checked by the examination of other features, and particularly those relating to the propagative organs.

II. Examination of the *internal structure* of the adult for purposes of comparison followed tardily upon the study of external form. Stimulated by the invention of the microscope, anatomy was well advanced in the early part of the last century, but it has made very rapid strides in recent decades. The comparative value of anatomical detail depends upon the degree of stability shown by the tissues of plants, and it is especially in the vascular system that reliable grounds for comparison are found. In particular it is in the more primitive land-plants, such as the club-mosses, horse-tails, and ferns, that this study has yielded evidence of the greatest value; and that not only in living forms but also in related fossils, in which these resistant tissues are apt to be well preserved.

III. The *study of ontogeny*, that is, observation of the development of the individual from the egg onwards, gives added interest to the external and internal characters of the adult. Schleiden early in the nineteenth century was the first to insist upon the importance of this in botanical science. For him the history of development was the foundation of all insight into morphology. His method soon bore splendid

fruit in the researches of Hofmeister, which will be referred to later. But unfortunately its application led to errors which sprang from the very success of ontogenetic study as applied to animals. Their development and embryology are discussed in Chapter XIV of *The Origin of Species*. Darwin there concludes that "embryology rises greatly in interest when we look at the embryo as a picture, more or less obscured, of the progenitor, either in its adult or larval state, of all the members of the same great class". Since the view that the ontogenetic history of the individual thus reflects in some degree the evolution of the race was found applicable in general terms for animals, it was assumed that it should be applicable also for plants, and many attempts were made to interpret their embryology also from this point of view. Undue weight was given to the details of early segmentation in the effort thereby to read an epitome of racial history. Several decades elapsed before it was fully realized that an inherent difference exists between the embryology of animals and that of plants. In the higher animals the embryology is carried out once for all at the outset of individual development: the limbs are laid down, and no further members are normally formed. But in plants the formation of new members is continued throughout the whole of active existence. The initial steps in the animal define the ultimate structure: in plants they may be merely a passing phase, determining neither the number nor the position of the definitive parts. Hence the so-called law of recapitulation might be assumed to apply less stringently in plants than in animals, and detailed comparison shows that this is actually the truth. Nevertheless comparative importance should still be accorded to observations of individual development in plants, though the results cannot be read with confidence into terms of phyletic history.

On the other hand, as soon as the ontogenetic study was extended to the whole life-cycle of plants important facts emerged; and this was particularly seen in the pioneer-observations of Hofmeister. That great observer, by a rigid comparison of the completed life-histories of the Archegoniatæ

demonstrated that a close unity of scheme underlay them all. Liverworts, mosses, ferns, club-mosses, horse-tails, and gymnosperms were all shown by him to have the same main framework within which their individual development is comprised. Hence, as Sachs so well remarked in his *History of Botany*[1]: " When Darwin's theory was given to the world eight years after Hofmeister's investigations, the relations of affinity between the great divisions of the vegetable kingdom were so well established and so patent, that the theory of descent had only to accept what genetic morphology had actually brought to view ".

The critical morphologist of the present moment may not wholly endorse the opinion thus enthusiastically stated. There is, indeed, a strong disposition among current writers to question whether the evolutionary relations of the great divisions of the vegetable kingdom are so close as they were thought to be in the decades that immediately succeeded the publication of *The Origin of Species*. Though it has since been shown that angiosperms on the one hand, and certain algæ and fungi on the other, share a modified type of life-cycle with alternation like that demonstrated by Hofmeister for ferns, a cooler judgment does not now admit that this necessarily demonstrates a near affinity. May it not really imply some parallel or homoplastic reaction to limiting factors of life that have been common to all? It is significant that a more exact knowledge of the earlier fossil floras has hitherto failed to unite the several divisions, so as to form that common " evolutionary tree " that hovered in the minds of those directly influenced by the enthusiastic writing of Haeckel. In particular the recognition of the Pteridosperms as very early seed-plants which have a history that may be traced back as far as or perhaps even further than that of the true ferns themselves, has rudely shaken facile beliefs in common origins. It has been graphically stated that the present view of lines of descent for vascular plants is more like a bundle of sticks than a connected tree. In fact, notwithstanding the demonstrated unity of plan in the

[1] Oxford Press, English edition, 1890, p. 202.

life-history of archegoniate plants, the morphological problem of descent is regarded by many as being again in the melting-pot, and genetic morphology itself tends for that reason to be discounted in the minds of its critics, and sometimes even of its professed adherents.

IV. Meanwhile other lines than those of structural, comparative, and developmental morphology have been brought into the field of inquiry upon which evolutionary views may be based. The whole *science of genetics* has sprung up, which is founded upon the nucleus of the cell, its structure, and its behaviour in somatic division, in meiosis, and in syngamy. The number of the chromosomes that appear on division is found to be approximately constant in the species, and there is reason to believe that they maintain their identity throughout the resting period of the nucleus. But in each completed cycle that number is doubled in sexual fusion, and subsequently reduced again to one-half in meiosis; these being the critical points in each normal sexual cycle. Few facts in the later development of biological science are so imposing as the high degree of unity and of constancy in succession of the nuclear phenomena in both the kingdoms of living things. It leads to an alternation of the diploid and haploid states in each completed sexual cycle. With occasional exceptions this is the cytological framework upon which the evolution of sexually propagated organisms is based.

The first impulse may well be to assume this similarity of the sexual cycle as evidence of common descent. But is that evidence trustworthy? Before such a conclusion can be held as valid it would be necessary to be quite sure that sexuality itself was actually the same thing by descent in the two kingdoms of living things; in other words, that sexual propagation preceded in time the separation of these two kingdoms, supposing that they actually had a common origin. This latter supposition is in itself more of the nature of an assumption, or at least of a pious belief, than a matter of demonstration. How uncertain then must the further assumption be that the sexual cells themselves of the two kingdoms are truly homolo-

gous, that is homogenetic? The strong probability appears to be that they are not. Reasons for this conclusion are to be found in a rigid comparison of the simpler types of animals and plants, which yields abundant evidence of the origin of syngamy and of sexual differentiation separately not only in animals and in plants, but even in distinct families of each. Accordingly we shall be thrown back upon comparison, within either kingdom apart from the other, for trustworthy evolutionary evidence. The fact that the nuclear details of the sexual cycle are so similar in the two kingdoms may well be held as the most far-reaching example of homoplasy. One may marvel at the likeness of the details, but still be circumspect in the comparative use of them.

V. Another line of study, that of *palæontology*, serves as a check upon the conclusions of comparative morphology. The comparative examination of related fossils from successive geological horizons may be held as giving, so far as it is available, an epitomized history expressed in positive terms. The validity of this statement turns upon the word " related ", and this is in each comparison naturally a matter of opinion. But frequently the structural similarities are so clear, even between early fossils and plants still living, that the legitimacy of their comparison cannot be doubted. Stratigraphical sequences of forms so related—provided the comparisons be reasonably founded—afford knowledge which may be held as positive. It is from this source that the conclusions of comparison between living things may often be most effectively tested.

VI. *The problem of evolution is in its essence physiological.* Many of the lines of inquiry involve the study of those vital processes by which the race may have come into existence and the individual have developed to the adult state. But such inquiries can only be carried out on organisms now living. Hence experimental study of such processes cannot be held as reflecting with certainty the events of the distant past. Experiment itself on things now living cannot safely be held as material for reconstructing their evolutionary history: for it is impossible to arrange for purposes of experiment all the con-

ditions on the exact footing of an earlier period. Physiological observation may therefore be held as providing a basis of probability of earlier evolutionary events rather than a demonstration of them. These remarks apply in particular to experiments affecting the balance of sterile and fertile regions of the sporophyte: the experimental induction of apospory: and other experiments bearing upon the balance and relations of the alternating generations.

The most fruitful physiological experiments of recent times have been those in artificial breeding. By combining the Mendelian method with exact cytological observation it has been possible to establish far-reaching views as to heredity. These have been successfully submitted to the test of synthetic and analytic experiment by actual breeding, with results which have even brought economic success, as in the case of home-grown wheats. Nevertheless Dr. Bateson himself admits that the Mendelian analysis has not given us the origin of species; but he concludes that henceforth the study of evolution is in the hands of the cytologists, in conjunction with the experimental breeder.[1]

Various Uses of these Lines of Inquiry

According to the mentality of the inquirer, one or another of these avenues of thought may be given the precedence. To the physiologist the process of individual development, and the play of conditions, immediate or hereditary, may take the prior place. To the student of heredity the results of breeding experiments will have special weight, interacting closely with cytology. To the morphologist and palæontologist the record of past processes of development, as shown in the form and structure actually achieved—such results stretching back, by comparison of living and fossil beings, to the remote past—appears to offer the most direct key to the riddle of evolution. But the results of all of these methods should be co-ordinated, and the scientific inquirer should be cognisant of them all.

[1] *Nature*, May, 1924.

The Origin of Species was written before exact knowledge of nuclear detail or Mendelian experiment existed. At that time plant-palæontology also was in its infancy. Though Darwin took the widest view of his problem possible at the time, it was inevitable that comparative morphology should figure very prominently in his argument. In Chapter XIV he describes it as "the most interesting department of Natural History, and it may be said to be its very soul". The publication of *The Origin of Species* at once stimulated it to an activity never known before. But the tendency of more modern writers on evolution has been to swing over to later methods of attack, and morphology is apt to fall, or even to be thrust forcibly into the background. It seems therefore desirable to state the actual morphological facts for some concrete class of plants well represented by living genera and species, having well-marked and variable features, and possessing a long palæontological history that can be followed backwards by consecutive steps to the Primary Rocks. The class of living plants that best answers all these requirements is the Filicales, or Ferns. They may therefore be taken as an example of modern phyletic study, open to illumination along all those lines of inquiry mentioned in the preceding pages.

Study of Ferns as an Example of Phyletic Method

In accordance with the dictates of a Natural System of Classification, which are actually those of comparative morphology in the widest acceptance of the term, it is desirable to make the basis of that classification as wide as possible; in fact to extend the criteria used. These should be taken from both of those alternating generations which constitute the life-history of any modern fern. But while the living material may readily supply the necessary facts for both generations, the fossil evidence relates almost entirely to the fern-plant, or sporophyte generation. The criteria drawn from this source in living ferns may then be checked by comparison with early fossils, back even to the Primary Rocks. But in the gametophyte generation, or prothallus as it is called, the fossils give

virtually no aid; and the comparisons drawn from its delicate structure must remain, for the present at least, unchecked.

Criteria of Comparison for Ferns

The following are the criteria of comparison which have been found most suitable for use with a view to the phyletic seriation of the Ferns:

SPOROPHYTE
1. The external morphology of the shoot.
2. The initial constitution of the plant-body as indicated by segmentation.
3. The architecture and venation of the leaf.
4. The vascular system of the shoot.
5. The dermal appendages.
6. The position and structure of the sorus.
7. The indusial protections.
8. The characters of the sporangium, and the form and marking of the spores.
9. The spore-output.

GAMETOPHYTE
10. The morphology of the prothallus.
11. The position and structure of the sexual organs.
12. The embryology of the sporophyte.

According to these criteria the whole class of the Filicales may be seriated roughly into those that are of more massive construction as distinct from those that are more delicate, but with many gentle gradations between the extremes. The former have been designated the *Eusporangiate Ferns* because their sporangia are relatively massive, and that feature serves as a general indication of their habit; the latter are called the *Leptosporangiate Ferns* because their sporangia are relatively small and delicate, a feature that accords also with their general construction. Seriated thus according to mass and texture—which is found to work out in accordance with the other criteria of comparison—the question arises whether or not either of these distinct types is to be held as the more primitive, and the other later and derivative. Here palæontology steps

in with a decisive answer, as the following facts will show.

Early writers on ferns, taking their stand on comparison, and seeing some superficial resemblance between the Filmy Ferns (Hymenophyllaceæ) and the delicate structure of the Mosses, suggested an affinity between them. The later discovery of the filamentous prothallus of the Filmy Ferns, and its comparison with the protonema of Mosses, appeared to confirm this position. But it is now fully admitted that the filmy character of the leaf and the filamentous prothallus, together with other vegetative features, may all find their explanation as secondary adaptations to life in very moist conditions. Those who advanced the comparison of Filmy Ferns with Mosses had no difficulty in placing them lowest in the scale of the Filicales. Presumably then from an evolutionary point of view they should have been the first to appear in stratigraphical sequence. But these writers did not take the palæontological evidence into account, and indeed such evidence was not yet available for them, as it is for us to-day.

Application of the Palæontological Check

Already in 1890 Campbell had argued, on the basis of comparison, that the relatively robust Eusporangiate Ferns really represent a primitive, and the more delicate Leptosporangiate Ferns a later and derivative type, and the advance of palæontological evidence has tended to confirm his conclusion. The dearth of proof of the early existence of true Leptosporangiate Ferns in the Primary Rocks, comparable to those so prevalent at the present day, was long ago pointed out. At the same time the existence was shown in the Carboniferous Age of many fossils resembling the Marattiaceous Ferns, and this was held to indicate clearly the priority of the Eusporangiate type. Though many of those fossils which were drawn into these early comparisons have since been shown to be primitive seed-plants (Pteridosperms), there still remain the Botryopterideæ and Zygopterideæ, and various other types which prove the existence of homosporous Eusporangiate Ferns in the Palæozoic Period. On the other hand Dr. Kidston, with full know-

ledge of the palæontological facts up to 1922, remarks guardedly that " one is certainly not justified in saying that a sporangium of Carboniferous Age, with annulus formed of one row of cells, did not exist; yet the existence of such an annulus at that date has not been satisfactorily demonstrated, and I think this point requires careful re-examination ".[1] The sporangia of typical Leptosporangiate Ferns have only a single row of cells. So also have some of those early intermediate types, such as the Schizæaceæ, Gleicheniaceæ, and Matonineæ, which flourished in Mesozoic times. Some such intermediate types may well have been represented also in the Carboniferous Age. But the advanced Leptosporangiate Ferns, which are the prevalent types of the present day, were not characteristic of Palæozoic times; it appears even doubtful whether the intermediate types existed at that period. The ferns of the Primary Rocks appear to have been mostly, and perhaps exclusively, typical Eusporangiates, a fact which supports Campbell's comparative conclusion. If this be admitted, then we may contemplate for the Filicales a progression, confirmed by early fossil evidence, from a more massive and complex to a simpler but more exact plan of construction; in fact, *a general progression from typically Eusporangiate to typically Leptosporangiate Ferns.*

Ferns represent a Skein of Advancing Lines

Between the extremes characterized primarily by their sporangia the Ferns Series may be laid out, not as a simple linear sequence, but as a great skein or fan of advancing lines. We need not be surprised to find difficulty in connecting those lines together into a continuous " tree ". The real interest will be seen to lie in the general progression, repeated in a plurality of lines, and involving other characters than the sporangia themselves, from a more massive type held as primitive to a less massive type held as derivative. In fact there is evidence of a general *phyletic drift* towards a more exact and delicate construction as the evolution of the Filicales progressed.

[1] " Fossil Plants of the Carboniferous Rocks ", *Mem. Geol. Survey,* Vol. II, Part 4, p. 278.

Results of Comparison in Respect of the Several Criteria

The nature of the evolutionary sequence of the Filicales, thus broadly indicated by the fossil evidence, will be best appreciated by an epitome of the results obtained by comparison in respect of the several criteria enumerated above. These will be taken seriatim.

1. The *shoot of ferns*, composed of axis and leaves, is essentially of the same construction as in vascular plants at large, and its apical growth is indefinite. The upright radial type is probably primitive, and the dorsiventral derivative; but the latter was certainly acquired early, as shown by some fossils. The branching of the shoot may be referred to dichotomy with equal or unequal development of the resulting shanks. When very unequal the appearance may be that of axillary budding. But equal dichotomy, which is probably the primitive type, is common (fig. 1). Those shoots which fork equally may then be held as primitive in that feature, and any departure from equality may be held as derivative.

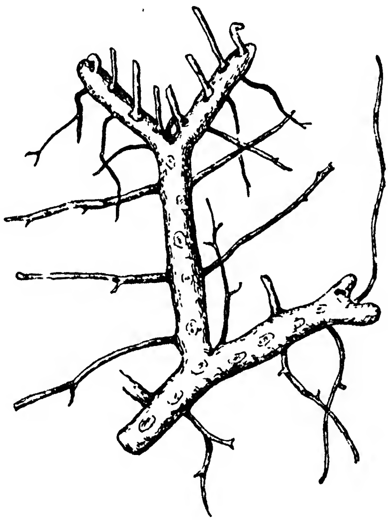


Fig. 1.—The dorsiventral and dichotomous rhizome of *Lygodium scandens*, showing repeated forkings. The leaves are arranged apparently in a single row, though really alternate, and the roots are attached irregularly. (After Velenovsky.)

2. The construction of the plant-body and its parts is initiated by *apical growth*, which may be indefinitely continued in axis and root, though it is usually (but not always) limited in leaves and pinnæ. It is carried out in ferns by initial cells, often of very definite form and number, and regular in seg-

mentation. In the Eusporangiate Ferns, though there may be at times a single initial in stem, leaf, or root, there is usually a plurality, such as three or four (fig. 2). Also the lateral wings of the leaf are massive from the first. All these states correspond in their complexity of segmentation to that of the massive sporangia, which arise each from a group of cells. But in the Leptosporangiate Ferns there is constantly a single initial in stem, leaf, and root, and the wings of the leaf arise from a single row of marginal initials. These more simple and definite segmentations correspond to those seen in their delicate sporangia, each of which arises from a single cell (fig. 3, *a*, *b*). Thus the sporangia themselves are an index on the one hand of the more massive construction seen in the Eusporangiatæ, which palæontology indicates as primitive: on the other hand, of a more delicate construction as seen in the Leptosporangiatæ, which may be held as the later and derivative type of construction.

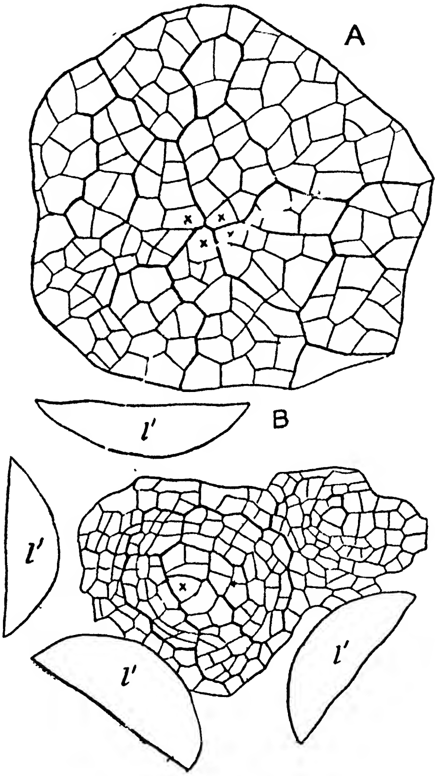


Fig. 2

A, Apex of the Stem of *Angiopteris evecta* seen from above. Apparently there are four initial cells, which are marked each with a cross (× 83).

B, Apex of Stem of *Osmunda regalis*, seen from above, showing the apical cells of stem and youngest leaf: *l′ l′* are the older leaves. The successive segments of the apical cell form the whole of the apical cone (× 83).

3. The *leaves of ferns* are the most prominent members of

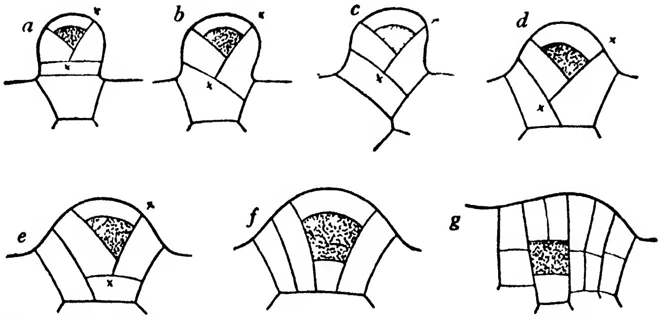


Fig. 3.—Diagrams illustrating the Segmentation of the Sporangia in various Ferns

a, *Polypodiaceæ*; *b*, *Ceratopteris*; *c*, *Alsophila*; *d*, *Schizæa* or *Thyrsopteris*, or *Trichomanes*; *e*, *f*, *Todea*; *g*, *Angiopteris*. *a* is a typical Leptosporangiate Fern; *g* is a typical Eusporangiate Fern; *d*, *e*, *f* show intermediate states between the two.

their vegetative system, and they provide external characters of great value for seriation. There are three avenues for study

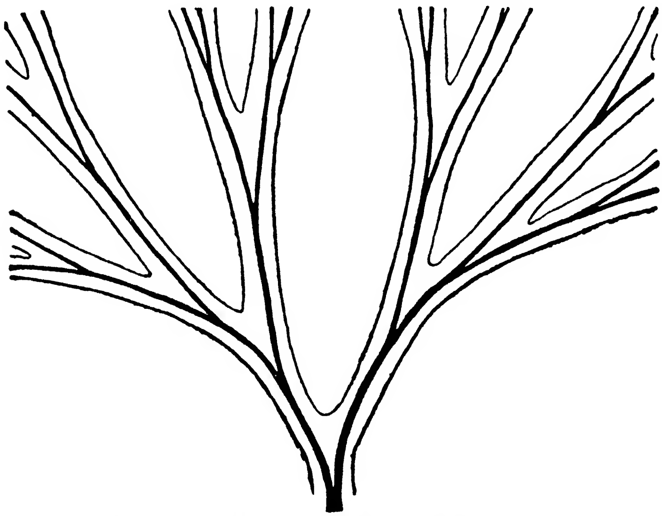


Fig. 4.—Basal part of the lamina of an adult sterile leaf of *Elaphoglossum* (*Rhipidopteris*) *peltatum*, showing very perfect dichotomy (× 4)

of leaves which may lead to a knowledge of the principles that have ruled in their evolution: (i) comparison of the juvenile

with the adult leaves of the individual—that gives the ontogenetic aspect of the problem; (ii) comparison of the detailed structure of the adult leaves in different genera and species; (iii) comparison of the stratigraphical sequence of related fossils. If the facts and the reasoning be correct the conclusions from them all should substantially coincide, as in this case they are found to do.

Such comparisons of the leaves of ferns living and fossil

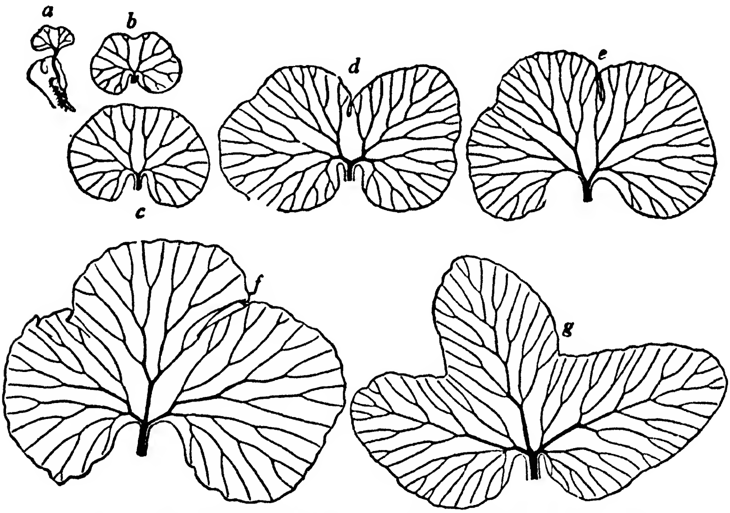


Fig. 5.—Successive juvenile leaves of *Osmunda regalis*, showing successive steps of progression from equal dichotomous venation to sympodial branching, and in *f*, *g* the establishment of a terminal lobe: but all derived by modification of dichotomous branching ($\times 2\frac{1}{2}$).

suggest that their architecture is built up by elaboration of a distal dichotomy of the blade, with in the first instance equal forking, a type of leaf-structure occasionally retained by them to-day in high perfection (fig. 4). In a primitive type recognized as the *Sphenopteris*-type, seen in certain early fossils and often in the Filmy Ferns of the present day, each narrow lobe contains only a single vein. This is also the state seen in fig. 4. A lateral webbing together of such lobes, but still showing dichotomy, would lead to a more effective expanse for nutritive

purposes, as may be seen in the sporeling-leaves of *Osmunda* (fig. 5, *a*, *b*, *c*). But a mere fan-like expanse of equal dichotomy is less effective than a more elongated form of the whole leaf, with leaflets borne laterally on the rachis (fig. 5, *d–g*). Such was probably the origin of all the prevalent types of leaf seen in early ferns. Thus far a separate course of the veins may have served well enough; but where a wide leaf-surface has been formed, occasional lateral fusion of the veins would provide for more equal distribution of water over the enlarged area, and a coarse network is the result (fig. 6). A structure still more effective physiologically is that where a smaller-meshed network fills in the areas of the coarser framework (fig. 7). The stratigraphical sequence of fossils shows that these progressive steps in physiological efficiency actually succeeded one another in geological time: for reticulation is unknown in Devonian plants; a coarse meshwork is first seen in the Middle Coal Period, but it was not till the Mesozoic Period that reticulation of a high order, with a small network within the larger meshes, became prevalent. From these facts it follows that open venation was primitive, and that there was a progression in time from coarser to smaller meshes.

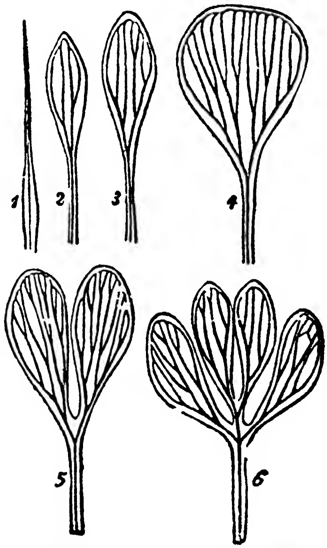


FIG. 6.—1 to 6, Successive types of juvenile leaves of *Marsilia*, after Braun. They show a dichotomous venation, but the veins are linked together by commissural arches within the leaf-margin.

As a result we find that though in ferns the leaves themselves as a whole have commonly reached the pinnate state, equal dichotomous forking of the veins, with free vein-endings, is characteristic of those ferns which are regarded on other grounds as primitive: but vein-fusions or even fine reticulation

may appear in those held on other grounds as advanced. Nevertheless a reticulate venation may occur sporadically in living

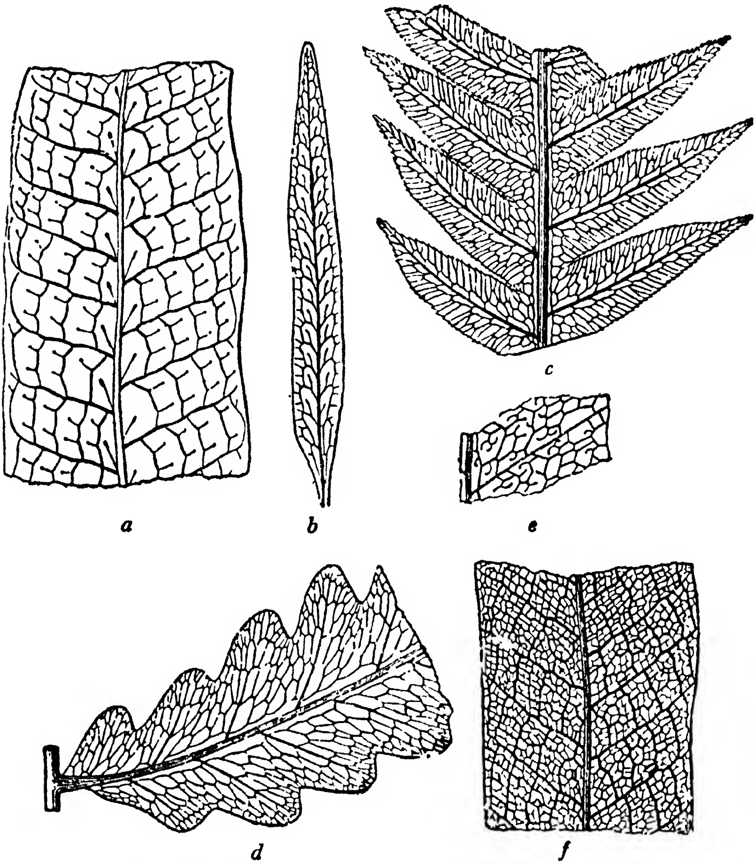


Fig. 7.—Examples of the venation of leaves of relatively advanced Ferns, showing various degrees of reticulation

a, *Polypodium cæspitosum*; *b*, *Polypodium serpens*; *c*, *Woodwardia radicans*; *d*, *Onoclea sensibilis*; *e*, *Polypodium crassifolium*; *f*, *Polypodium quercifolium*. Natural size, after Luerssen.

species of ancient families, such as the Marattiaceæ, Gleicheniaceæ, and Schizæaceæ: but only in isolated genera or species, and these may be regarded as late advances in that particular

feature. With such materials at hand the leaves of ferns aid greatly in their phyletic comparison.

4. The *vascular system of the shoot* bears a special value for comparison because of its phyletic inertia. Its characters persist, or are apt tardily to follow on progressive development. This is especially so in the stem. Again there are three avenues for attack on the comparative problem: (i) the facts of structure in the adult of the various types; (ii) the ontogenetic changes in the individual; (iii) the facts derived from related fossils. In studying the stelar structure in ferns it is to be remembered that with very few exceptions cambial increase is absent. As the young plant grows from the sporeling its stem takes a conical shape, enlarging upwards with the increasing size of the leaves that it bears; and the conducting tissues within enlarge proportionately. But as it does so the proportion of surface to bulk will be constantly changing, in the ratio of the square to the cube. This circumstance probably stands in intimate relation to the fact that in the larger ferns some of the most complicated vascular structures seen in the Vegetable Kingdom are found.

By general agreement the protostele, that is a conducting strand with a solid core of wood, is regarded as the primitive type for the stem. The fact that this is found uniformly in the sporelings of ferns accords with this view. Some ferns retain this structure through life, as do the most primitive fossils such as the Botryopterideæ. Among modern ferns the Gleicheniaceæ and Hymenophyllaceæ, which are relatively primitive types, are protostelic. But in most ferns the transition to the adult state brings increased size with added complexity. The first change is medullation, that is the formation of a central pith. A number of primitive ferns show further steps of a progressive disintegration of the vascular tracts into variously moulded and finally separate strands. This is related to increase in size, as successive sections of the same conically enlarging stem may show (fig. 8). But the degree of these changes does not directly depend upon absolute size alone; this is proved by drawings to the same scale from the stems of different ferns

(fig. 9). There are other factors at work, one of which is almost certainly the influence of an enlarging leaf upon the structure of the axis that bears it.

A like disintegration appears in the vascular supply of the leaf itself. Sections of the petiole show in the most primitive types an undivided vascular tract of oval outline. In later types,

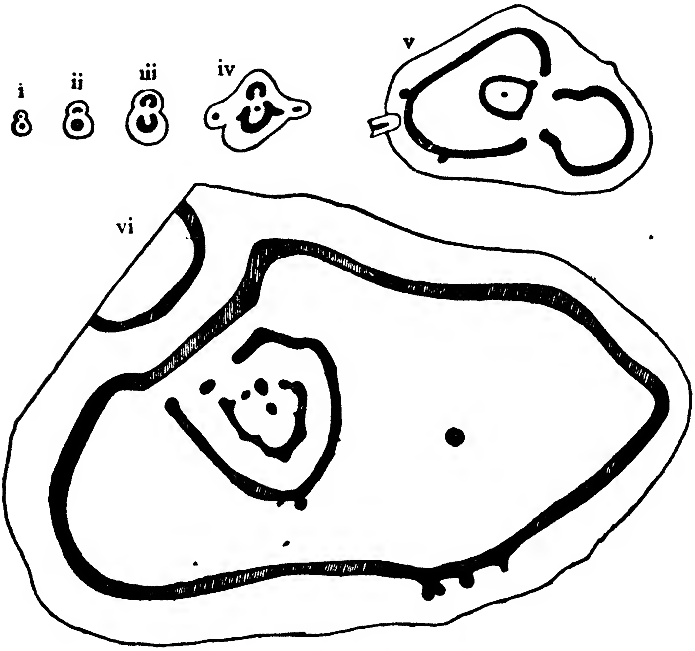


Fig. 8.—A series of transverse sections of the stem of *Pteris* (*Litobrochia*) *podophylla*, all drawn to the same scale, and showing the great increase in stelar complexity as the stem expands conically upwards. The vascular tissue is shaded (× 4).

or in the upper regions of the same individual leaf-trace, a gutter-like form appears, horseshoe-shaped in transverse section, which again in still more advanced types is seen to be disintegrated into smaller separate strands (fig. 10). Such changes in leaf and stem accompany the triumph of the Leptosporangiate Ferns, as witnessed by their 6000 living species, spread widely over the face of the earth. That triumph has been

won structurally by a compromise, effected without cambial increase in the enlarging shoot. The stele has maintained its endodermal barriers complete, and has overcome the difficulties of surface-interchange consequent on enlargement by various steps of moulding and disintegrating the conducting

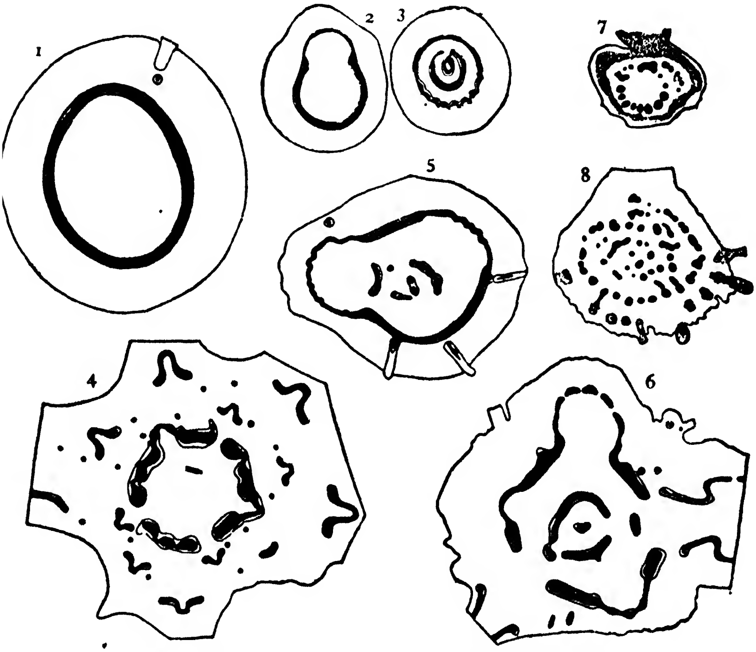


Fig. 9.—A series of solenostelic and dictyostelic Ferns, all drawn to the same scale (× 2)

1, *Metaxya*; 2, *Dipteris conjugata*; 3, *Matonia pectinata*; 4, *Plagiogyria*; 5, *Thyrsopteris elegans*; 6, *Saccoloma elegans*; 7, *Platycerium alcicorne*; 8, *Platycerium Œthiopicum*. These drawings show that the disintegration of the stele does not depend on absolute size alone.

tracts. Clearly there is here material in plenty for phyletic treatment. The degree of disintegration of those conducting tracts may be held as giving trustworthy indications of the phyletic advance of the fern that shows it.

5. The *character of the appendages* covering the exposed surfaces of ferns has also its phyletic interest. Such primitive families as the Botryopterideæ, Ophioglossaceæ, Osmundaceæ,

and Hymenophyllaceæ have hairs simple or branched, but no scales. Flattened scales are, however, a common feature in advanced Leptosporangiate Ferns. Frequently the existence of simple hairs in genera of intermediate position serves to confirm other primitive features, and so helps to fix their systematic position, as in *Plagiogyria*, *Lophosoria*, and *Metaxya*. The effect of such ancillary facts upon the general argument is cumulative.

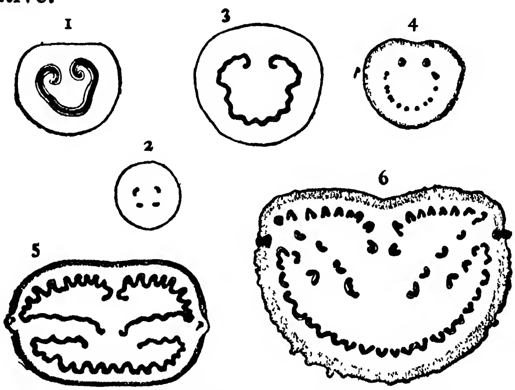


Fig. 10.—Transverse sections of petioles, all drawn on the same scale (× 2)

1, *Dipteris conjugata*; 2, *Dipteris Lobbiana*; 3, *Metaxya*; 4, *Phlebodium aureum*; 5, *Thyrsopteris*; 6, *Alsophila australis*. These show that while greater size leads to vascular disintegration, there is no definite proportion.

6. The *character of the sorus* naturally takes a prominent place in the phyletic classification of ferns. The sorus varies greatly in constitution, position, individuality, and in methods of protection. Three types of its constitution have been recognized: the Simple, the Gradate, and the Mixed. The first is characteristic of those ferns which both comparison and fossil history show to be the most primitive: in them all the sporangia are initiated simultaneously (Simplices). The prototype was probably the " monangial sorus ", where the sporangium is solitary and distal, as it is in the fossil *Stauropteris*. The Mixed condition is that which prevails at the present day, where sporangia of different ages are mixed up together, as in *Poly-*

podium or *Nephrodium* (Mixtæ). The Gradate state is found to take an intermediate place in many though not in all evolutionary lines of ferns. It is characterized by a succession of sporangia appearing usually in a basipetal succession upon an elongating receptacle, as in the Filmy Ferns (Gradatæ). (Fig. 11.) In the first type the physiological drain of nutrition is synchronous for all the sporangia: in the Gradatæ it is spread

Fig. 11.—Mature sorus of *Loxsoma Cunninghamii*, with the receptacle elongated so as to raise the sporangia, which are borne in basipetal sequence, above the tip of the cup-shaped indusium: here they open by a median dehiscence. (After von Goebel: ×25.)

over a lengthened period of time: and the same, though with greater convenience of nutrition, holds for the Mixtæ. Thus not only by comparison, but also by fossil history and by physiological probability, these three states may be held to illustrate successive steps in phyletic advance.

The marginal position of the sorus is found to be usual in primitive types, such as the Ophioglossaceæ, *Osmunda* (but not *Todea*), and the Schizæaceæ (Marginales). But in most of the advanced ferns the sorus is borne on the under surface of the

sporophyll, and there is ample evidence of its having executed a "phyletic slide", not once only but repeatedly in distinct phyla, from the margin to the surface (Superficiales). The biological advantage of the protection thus gained requires no insistence. There is also evidence both of the progressive fusion and fission of sori, which indicates that the sorus is not a constant morphological entity.

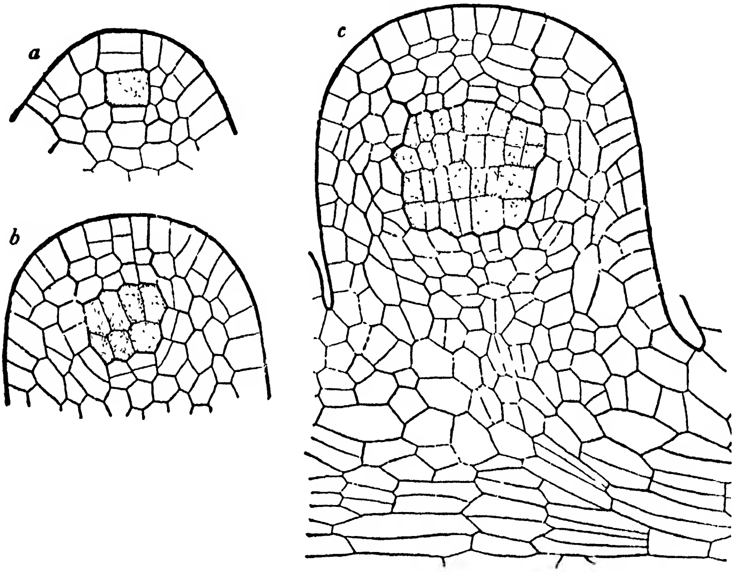


Fig. 12.—Three successive stages of development of the sporangium of *Botrychium daucifolium*, showing its massive stalk and multicellular origin. This is characteristic of Eusporangiate Ferns ($\times 250$).

7. Lastly, *the protection of the sorus* gives material for comparison. The Simplices have as a rule no organized protection of the sorus. In the Gradatæ there is frequently a cup-shaped indusium which protects the youngest and most delicate sporangia at the base of the receptacle that rises from its centre (fig. 11). In the mixed sorus the indusial protections are very various in form: but in the most advanced types they may be wholly dispensed with (*Polypodium*): the naked sorus may even be spread out widely over the surface of the leaf (*Acro-*

stichum). There is comparative evidence that both of these final conditions have been acquired not only once, but along a plurality of evolutionary lines.

8. Parallel with these general changes in the sorus, which it will be noted allow of or even involve an increase in number of the sporangia, goes the progression towards a smaller size of the *individual sporangium* together with greater precision of its opening mechanism, and a smaller spore-output from

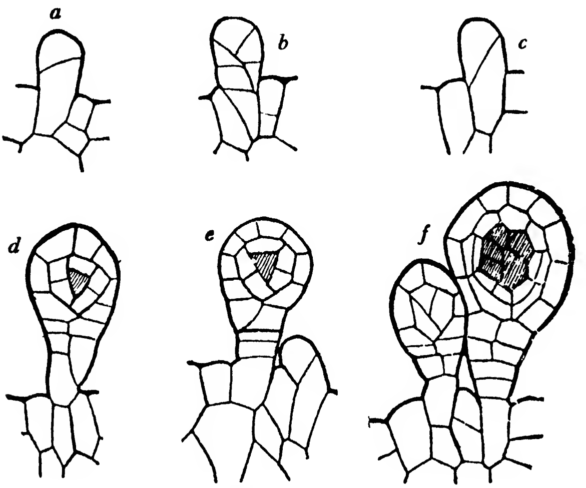


Fig. 13.—Stages *a* to *f* illustrate the development of the sporangium in *Phlebodium aureum*, which arises from a single cell. This is the characteristic of Leptosporangiate Ferns (× 200).

each. In fact there has been a transition by gradual steps from the primitive Eusporangiate to the derivative Leptosporangiate type. The sporangium of the former is massive from the first, and each may produce thousands of spores (fig. 12): the latter arises from a single cell, and each sporangium produces as a rule not more than sixty-four spores, and usually a still smaller number (fig. 13). It is impossible here to enter into the detailed steps of gradation which lead from one extreme of sporangial structure to the other, nor can the change be actually traced within the limits of any single genus or

family. It must suffice to say that a general progression runs from the massive types seen in the Simplices through intermediate Gradate types, to the Leptosporangiates. Roughly speaking the first are characteristically Palæozoic or Mesozoic, the last essentially modern. The transverse sections of the sporangial stalks give a good estimate of the gradual nature of the steps of structural transition, though those here shown do

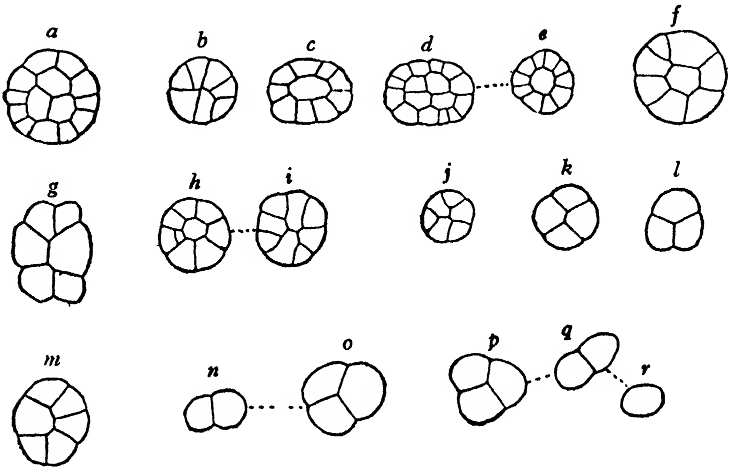


Fig. 14.—Series of transverse sections of sporangial stalks, showing steps of progressive simplification. All are approximately to the same scale (× 150).

a, *Gleichenia circinata*; *b*, *Gleichenia dichotoma*; *c*, *Mohria*; *d*, *e*, *Osmunda*; *f*, *Matonia*; *g*, *Loxsoma*; *h*, *i*, *Thyrsopteris*; *j*, *Cibotium culcita*; *k*, *Metaxya* and *Cheiropleuria*; *l*, *Platycerium*; *m*, *Plagiogyria*; *n*, *o*, *Elaphoglossum latifolium*; *p*, *q*, *r*, *Hypoderris Brownii*.

not include the most massive examples of all (fig. 14). The increasing precision of the mechanism of dehiscence, and its changes according to the constitution of the sorus and the size of the sporangium, are suggested by the series shown in fig. 15. It is apparent that the ring of mechanical cells is comparable in them all, but its position as well as the point of dehiscence—median or lateral—alters as the size of the sporangium decreases along the advancing sequence.

9. As a commentary upon this structural transition the

spore-output per sporangium may be quoted for a number of examples respectively of the Simplices, Gradatæ, and Mixtæ. Some of the figures are for the typical numbers that would result from the actual cell-divisions in the developing sporangia. Actual countings of the spores matured from individual sporangia show lower results, but still a near approximation to the typical numbers.

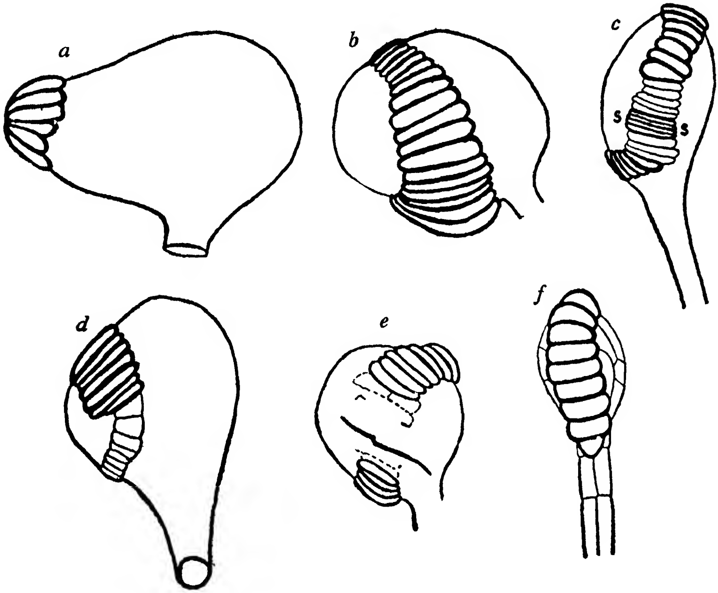


Fig. 15.—Sporangia of various Ferns, orientated so that the distal face is to the left, the proximal or basal to the right. This brings clearly into view the differences of proportion of those faces, and of the position of the annulus and stomium.

a, *Lygodium*; *b*, *Gleichenia*; *c*, *Plagiogyria*; *d*, *Loxsoma*; *e*, *Hymenophyllum*; *f*, *Leptochilus*; *s*, *s*, Stomium.

SIMPLICES	Marattia,	2500.
	Gleichenia,	256–1024.
	Osmunda,	256–512.
	Schizæa, Anemia, Mohria,	128.

GRADATÆ	Hymenophyllum,	128–512.
	Trichomanes,	32–256.
	Loxsoma,	64.
	Dicksonia,	64.
	Cyathea,	8–64.
MIXTÆ	Peranema,	64.
	Nephrodium,	48.
	Gymnogramme,	48–64.
	Pellæa,	24–64.
	Notholæna,	16–48.

Such figures show that there may often be a considerable range of variability within the genus in the typical numbers of spores per sporangium. Some of the genera here quoted were specially selected so as to bring out this point. Sometimes there may even be variation in the individual plant. But putting such minor fluctuations aside, it is clear that the Simplices with their massive sporangia and thick stalks have the highest average spore-output: the Gradatæ take a middle place both structurally and in spore-output: while the Mixtæ, which are delicate Leptosporangiates, have the lowest spore-output per sporangium. It is thus indicated that in the class of the Filicales there has been a progressive reduction in size of sporangia, in their complexity of structure, and in the spore-output, with increasing exactitude of the opening mechanism. Those types which palæontology shows to be the most ancient have relatively the largest spore-output, the Gradatæ take a middle position in time and in number, while the Mixtæ, which are essentially the ferns of the present day, hardly ever exceed sixty-four spores in each sporangium, and usually produce a smaller number.

10. The *prothallus* of ferns gives less reliable material for comparison as regards form and structure than the fern plant. The reason is that it is more directly plastic under external conditions than the fern-plant is, while its structure is much simpler. It is possible to refer most or perhaps all of its types

to an origin from a simple or branched filament. Some are actually filamentous (*Schizæa*, *Trichomanes*), and there are suggestions of transition to a flattened expanse, and of progress towards the symmetrical prothallus of the textbooks, which is the prevalent type. Many of the Eusporangiate Ferns have a more massive prothallus, in particular the Ophioglossaceæ. But these may be held to have been specialized in relation to mycorhizic nutrition, such a type being probably derived from a relatively massive green prothallus, such as is seen in the Marattiaceæ and Osmundaceæ.

11. With this massive structure of the prothallus in Eusporangiate Ferns goes a relatively bulky structure and often a sunken position of the *sexual organs*. Comparison within the Filicales shows that the archegonium was standardized early, assuming a degree of constancy that is seen even in primitive ferns, and precludes its taking anything more than a minor place in comparison. Its ventral part is always sunk in the tissue of the thallus, except in the simplest filamentous types. But there is some variation in the protrusion of the neck, which may be almost wholly immersed in *Marattia* or *Ophioglossum*. Beyond such details there is little scope for comparison. But with the antheridia it is different. Speaking generally they are deeply sunk in Eusporangiate Ferns but project in the Leptosporangiates, corresponding in this with their sporangia. There is further a rough parallel that may be drawn between the output of spermatozoids from the single antheridium and that of the spores from the single sporangium of the same ferns. This can be estimated roughly from the number of spermatocytes seen in a median section, and compared with the number of spore-mother-cells in a corresponding section of the young sporangia of the same ferns. The appended table gives some results, which are unfortunately restricted in number owing to the relatively few suitable published drawings of mature antheridia in section. It will be apparent that there is a real parallel between the antheridia and the sporangia; the numbers of productive cells in both being high in the Eusporangiate Ferns, but lower in the intermediate types such as

Gleichenia and *Osmunda*, and lowest in the Leptosporangiate Ferns.

Name.	Number of Spermatocytes in Vertical Section of the Antheridium.	Number of Spore-mother-cells in Vertical Section of the Sporangium.	Estimated Spore-output.
Ophioglossum pendulum	250 (Campbell)	500	15,000
Christensenia	74, 60 (Campbell)	74	7,850
Angiopteris	55 (Campbell)	67	1,450
Gleichenia flabellata ..	—	66	512–1024
Gleichenia lævigata ..	95, 76, 35 (Campbell)	—	—
Gleichenia dichotoma ..	42, 30 (Campbell)	26, 25	256 or more
Osmunda cinnamomea ..	32 (Campbell)	—	128
Hymenophyllum sp. ..	25 (Campbell)	--	128
Dennstædtia punctilobula	24 (Conard)	8	64
Trichomanes venosum ..	18 (von Goebel)	—	64 or less
Dryopteris Filix-mas ..	16 (Kny)	8 or less	48
Ceratopteris	7 (Kny)	—	32 or 16

It will be noted that a peculiar exception is found in *Ceratopteris*, and the same holds for *Schizæa*. Apart from these the parallel between organs apparently so distinct as the sporangium and the antheridium yields convincing support to the idea of a general progression from a more robust and ancient type of construction, the Eusporangiate, to a more delicate and modern type, that of the Leptosporangiate Ferns.

12. In the formation of the *embryo* of ferns the first step is the definition of its polarity. It may be regarded from the first as a simple leafy shoot upon which the suctorial organs, viz. foot and root, are accessory; but neither of these is always present. It is constructed as a spindle of which the apex grows directly into the axis; the base is in certain of the primitive Eusporangiates an organ called the suspensor. There are two main features on which phyletic comparison may be based: one is the relative complexity of the initial segmentations; the other is the presence or absence of a suspensor. In both respects the Eusporangiate is distinguished from the Leptosporangiate type: for the former shows more massive construction from the first, with less definite segmentation, while the embryos fre-

quently possess a suspensor (*Helminthostachys*, *Botrychium* sp., *Danæa*, *Christensenia*, and *Angiopteris* occasionally), while the latter show more delicate and regular segmentation, and no suspensor has yet been demonstrated in any of them. If the view be adopted that the suspensor is the base of a " primitive spindle ", then the Eusporangiates appear to be relatively primitive in possessing it, and the Leptosporangiates derivative in respect of its absence. Such a view accords with their palæontological history, while the more delicate structure and more definite segmentation of the embryos of the latter accord with that of all their vegetative organs, and of their sporangia.

General Conclusion from the above Comparisons

These paragraphs embody in condensed form the main results obtained from a very wide comparison of ferns, in respect of the twelve criteria specially selected as suitable for systematic use. The number of these may be added to as knowledge increases, or occasion requires. The interest of such comparisons is greatly enhanced when we put together those results, and attempt to draw from them some general conclusion. It is then found that they run substantially parallel, though not always so in respect of all of the criteria. For instance, by their use we may broadly distinguish the type of the Eusporangiate Ferns, and contrast it with that of the Leptosporangiate. Thus in *Botrychium* we find an upright shoot, massive from its first segmentations: open venation with prevalent dichotomy of the veins: the stele not far advanced from a protostele (in fact a medullated protostele); leaf-trace undivided at the source: hairs simple or absent: sporangia isolated on the ends or margins of the sporophyll-segments: of simultaneous origin: no indusium: eusporangiate, with thick stalks and primitive dehiscence: very large spore-output: massive prothallus: sunken sexual organs: antheridia with numerous spermatocytes: embryology massive, sometimes with suspensor: no clearly defined foot, and with root formed late.

On the other hand in *Polypodium* we find a shoot commonly elongated and creeping, with exact apical segmentation of stem, leaf, and root: reticulate venation: vascular tracts of stem and leaf highly disintegrated: broad scales as dermal coverings: sori of "mixed" type, with densely crowded sporangia produced in long succession: sporangia with long stalks, and exact dehiscence: small spore-output from each: delicate prothallus: sex-organs projecting, relatively small output of sperms: embryology delicate, and precise in segmentation: no suspensor: foot clearly defined, and with root originating early.

It might at first sight appear probable that the whole class might be disposed in a linear sequence between extremes so divergent. But any attempt to do this soon discloses difficulties which indicate very clearly that it is not a question of a single line, but of a brush composed of many minor lines, which however often appear from comparison within the near circle of affinity to be themselves recognizable as minor lines of advance. Certain genera or species of some well-defined affinity appear to be advanced beyond the rest in some single character or more. It is thus possible by the use of the criteria within the family or genus to lay out minor sequences. Sometimes a marked external character may suggest indefinite advance, such as that from open venation to reticulation. For instance *Christensenia* among the Marattiaceæ has reticulate venation; but this goes along with a leaf-form clearly specialized for growth in shade, and synangial sori. *Hypoderris* among the Woodsieæ shows a like character of venation, but in a quite distinct family which again has open venation as a rule. The leaf of *Ophioglossum* is reticulate among the Ophioglossaceæ, which have generally open venation: sections of the genera *Gleichenia* and *Lygodium* are reticulate. In fact quite a number of distinct families and even genera suggest that this structure has been achieved many times over in the descent of ferns. This is merely an instance of the homoplastic evolution that is written large across that general progression of the Filicales which is so clearly indicated as leading from the ancient Simplices to the modern Mixtæ.

How then from the evolutionary point of view are we to regard this progression carried out in so many distinct lines? The frequency of homoplasy gives the impression of a general phyletic drift made up of many varietal or specific changes, which can only have been achieved independently of one another in the several minor phyla that show them. We may take refuge in the beneficent word " adaptation ", and may exercise our ingenuity in the attempt to account for what we see by fitting effect with cause. No doubt some of the guesses that are made to this end may be near to, or may even actually hit the truth. But can anyone assert that this will always be a true or a complete explanation? Is it sufficient to cover all the complex facts? Would it not be better to attempt some more general analysis of the influences effective in producing the evolutionary results that we see?

Impulses and Limitations Operative in Evolution

The most important factors operative in the evolution of living things may be grouped under four heads:

(i) The *initiative* present in all organic life to develop.

(ii) *Limiting factors* that control the results.

(iii) *Syngamy* and *Mendelian segregation* that distribute those results.

(iv) *Natural selection*, which determines their survival or failure.

Of these (iii) and (iv) need not be discussed here, for they do not produce new features, but only distribute, select, or annihilate them. Our immediate interest lies in the origin and limitation, not in the manipulation of characters. Here we need only consider (i) and (ii).

(i) The consequences of the all-pervading initiative of living things to develop are seen primarily in an increase in size of the individual; secondly, in an increasing complexity of its form and structure; thirdly, in its variation of detail as shown by comparison of individuals or races. It is upon these variations that the theory of evolution is based, and the question at once arises of their origin and transmission. On the latter point

variations are ranged in two categories: (*a*) *fluctuating variations* which appear to leave no permanent impress so as to affect the reproductive cells: consequently they are held as not being hereditary; (*b*) *mutations* which are heritable, the qualities having been in some way impressed upon the gametes, so that they are transmissible to the offspring. The line of distinction between these has often been sharply drawn, and it has been stated generally, or adopted as a fact of experience, that characters acquired during the lifetime of the parent are not transmitted to the offspring. Nevertheless both mutations and fluctuating variations produce changes which may be held as "adaptive" to the external conditions. Naturally the characters that are actually heritable alone take their part in evolution.

The question of the *origin of heritable characters or mutations* is still quite an open one. The negation by Weismann of the inheritance of acquired characters was based chiefly upon zoological evidence. The early segregation of the germ-cells in animals weighed greatly with him and his followers. But it needs to be stated explicitly that in plants such early segregation does not occur. In them the tissues, still undifferentiated as somatic or as germ cells, are for long exposed to whatever the conditions of life may have been before the gametes are specialized. This suggests that plants would be particularly favourable subjects for observation in testing the point. It is a question not of dogma, but of probability based upon evidence. Frankly it must be admitted that the experimental evidence up to the moment is insufficient for full demonstration that acquired characters are heritable. Nevertheless many botanists have resolutely refused to accept the theory of Weismann. It seems to them better to entertain the possibility of some acquisition of heritable mutations than positively to deny it; for the difficulty in explaining in any other way the prevalence of an apparently adaptive character in those features that are heritable seems overwhelming. Such results as are observed have in earlier discussions on evolution been set down to selection of favourable divergences from type out of heritable

variations produced at random. But the prevalence of parallel development, or even of convergence of characters that appear adaptive, suggests that the mutations upon which they have been built up were not produced at random. They suggest that the origin of the mutations may be directed by some internal or physiological adjustment. They may, indeed, have been promoted or actually determined in their direction, or their number, or their quality in some way by external conditions. But these need not necessarily have worked within the restricted time-limits of present experiment; for the wide latitude of geological time has been available for evolution to proceed.

Importance of the Long History of Ferns

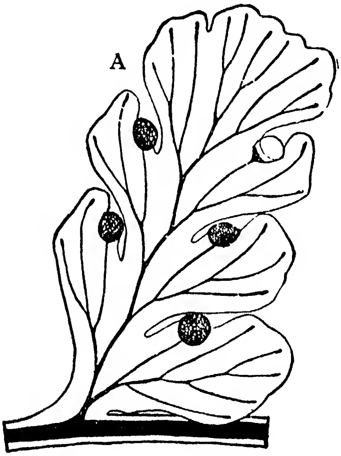
It is here that a great series like that of the ferns, with a long and consecutive fossil history, comes into the argument with singular force. Its comparative study has the advantage over immediate experiment of considering results acquired through long periods of geological time. The arguments of comparative morphology, checked or supported by reference to well preserved fossils, demand certainly no less attention than the experiments of the moment; for they deal with the actual results of evolution not only in progress now, but carried out during periods long past.

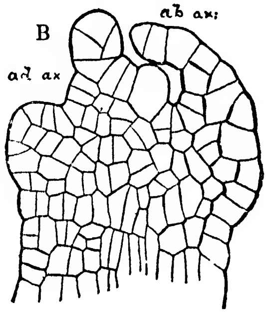
No one will doubt the essential unity of the great class of the ferns. Its record stretches back to the Palæozoic Rocks. One of its most striking features is the persistence of certain antique types among ferns now living. The Marattiaceæ and Ophioglossaceæ are held to represent in modern form certain Palæozoic types. But a nearer comparison lies with the Osmundaceæ, a family that is itself traceable back anatomically to the Permian Period. Some purists may still call in question the validity of these comparisons: but no one would be found to doubt the actual existence of Matonineæ, Schizæaceæ, and Gleicheniaceæ in the Mesozoic Period, with characters substantially similar to those of ferns now living. Their early existence as fossils confirms the comparative conclusion that the

Simplices are primitive types. With these ancient sources comparison links on a brush of evolutionary lines, each maintaining certain fundamental features distinctive of the families, but showing progressive homoplastic modifications: these features are seen in their external morphology, anatomy, dermal appendages, the position and constitution of the sori, the structure and output of the sporangia, the characters of the sexual organs, and the embryology. The several phyla illustrate in very high degree parallel development, showing advance not only in one or another of these features but in many of them, and sometimes in them all. How is this dominating homoplasy to be understood? A reference to such general expressions as " tendency " or " herd-sense " does not satisfy the mind, though it may sooth it. The facts show that, whatever the cause, there has undoubtedly been a common effect in the homoplastic evolution of organisms which have presumably been subjected to common conditions. Are we justified in regarding the common effects, worked out in long ages, as a reaction similar in them all to those common conditions? The difference between this age-long experiment and a laboratory or breeding experiment of the present day is in the essential factor of time. We may grant that though the direct and immediate effect of external conditions in producing adjustment of structure is not obviously heritable in the individual, yet the effect continued through long ages may become ultimately apparent in the race. In some such view as this the broad results in ferns appear to find a reasonable explanation.

No single homoplastic change in the ferns points to this more clearly than the shifting of the sorus from the margin of the sporophyll, which comparison of the most ancient types suggests as its pristine position, to a place on its lower surface which may be held as derivative and physiologically advantageous. There is reason to believe that this change has happened in many distinct phyla, sometimes early in evolution (Marattiaceæ, Gleicheniaceæ), sometimes it appears to be now in transition (Pteroideæ), but in others the marginal position is strictly maintained (Hymenophyllaceæ). The most illuminat-

ing results come from ferns that are in a state of transition, such as the Pteroideæ. In the more primitive Pterids the receptacle of the sorus is actually marginal, as it is also in the allied Dicksonieæ, but with unequal development of the indusial lips. This inequality becomes marked in *Dennstædtia* (fig. 16), the lower being the smaller. In *Hypolepis* the lower indusium is absent, or only vestigial, and the sorus





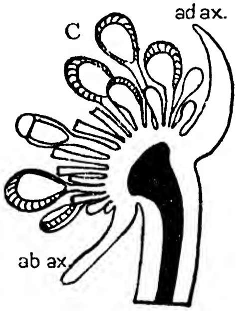


Fig. 16.—A, Pinnule of *Dennstædtia dissecta* seen in surface view, showing the marginal sori on the apices of the anadromic branches of the veins (×4). B, Sorus, very young, cut in vertical section, showing the marginal receptacle with the oldest sporangium on its tip, and the superficial indusial flaps, *ab. ax.* and *ad. ax.* (×150). C, Mature sorus in vertical section (×35).

becomes superficial on the leaf-expanse, now enlarged by the addition to it of the upper indusial lip (fig. 17). This is the condition seen in the fern described as *Polypodium punctatum*. A parallel but distinct series is seen in *Pteridium*, the bracken, in which the origin of the sorus is marginal (fig. 18). and *Pteris*, where it is actually superficial (fig. 19). The interpretation in both of these parallel examples is that a *phyletic slide of the sorus from the margin to the surface is*

seen in actual progress: that it is adaptive as a means of securing protection during development. Sometimes that adaptation may be seen in mere curvature of the individual margin during development of the individual, with inequality of the indusial lips (*Pteridium*); but that state may become inherited and permanent (*Pæsia viscosa* and *scaberala*), together with abortion of the lower lip (*Pteris*). This result is thus the same as in the parallel but distinct series, *Dennstædtia-*

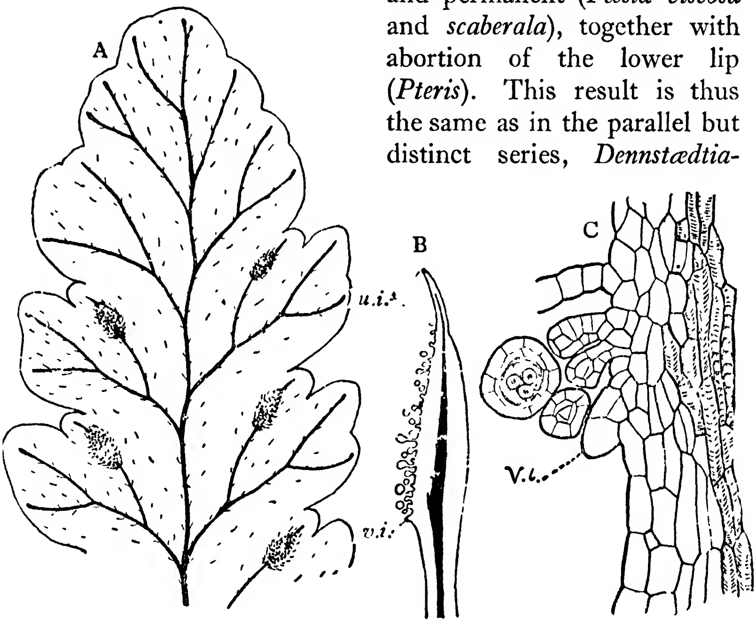


Fig. 17.—A, Pinnule of *Hypolepis repens* seen in surface view (× 10). B Young sorus of *H. repens* cut vertically, and showing the elongated receptacle *u.i.* (upper indusium) traversed by a vascular strand; *v.i.* is the vestigial lower indusium (× 15). C, A small part of its soral surface including the vestigial indusium (*v.i.*), more highly magnified (× 160).

Hypolepis, which actually culminates in a fern described as *Polypodium punctatum*, though this is really nothing else than a fully superficial *Hypolepis*.

These facts cannot fail to convince those who have followed the series by observation that a transition has taken place, and in some forms that it is actually in progress. They illustrate parallel steps in progressive adaptation in two related but

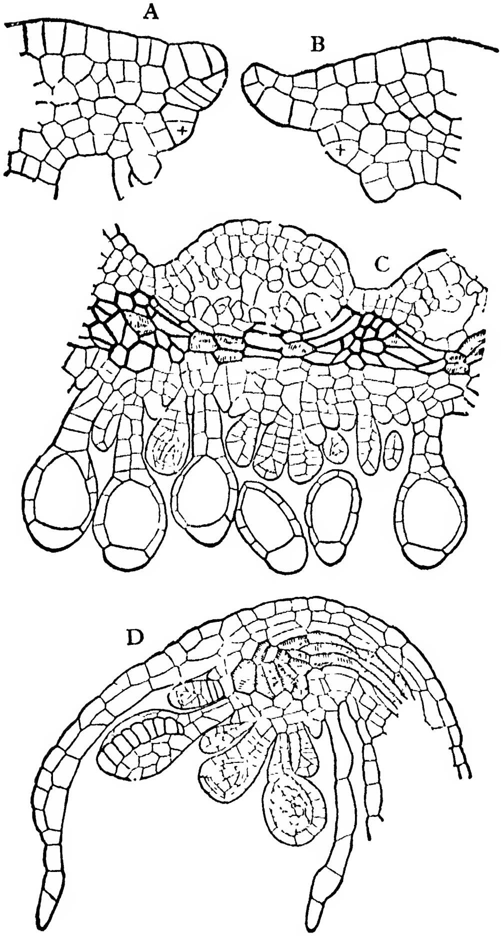


Fig. 18.—A, B, Vertical sections through the margin of the pinnule of *Pteridium aquilinum*, showing how the receptacle (x) originates directly from the marginal segmentation, while the indusial flaps are of superficial origin ($\times$ 180). C, Vertical section of the fusion-sorus of *Pteridium*, following the line of the vascular commissure ($\times$ 90). D, Section of a sorus more mature than A or B, but in a similar plane ($\times$ 90). C and D show the mixed character of the sorus.

distinct series of ferns. Those progressions are readily intelligible steps in homoplastic adaptation, by inheritance of an

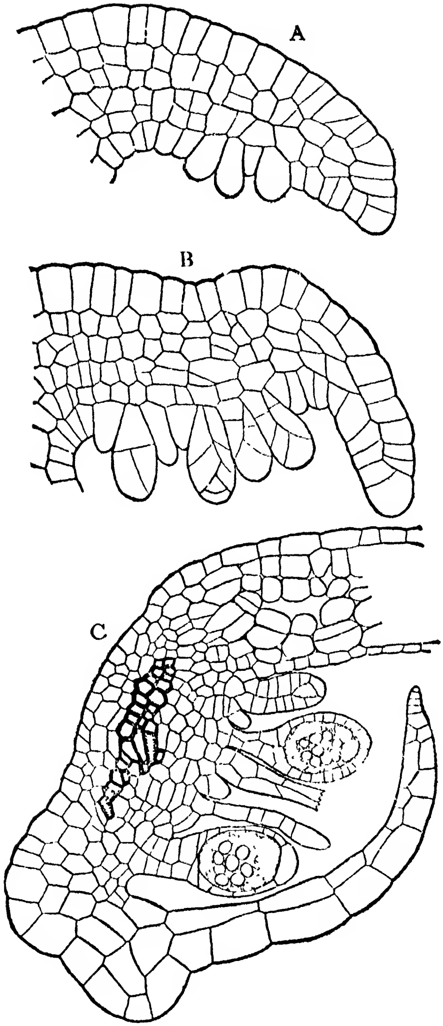


Fig. 19.—A, B, Vertical sections through young sori of *Pteris serrulata* (× 150). C, A similar section through a nearly mature sorus of *Pteris cretica* (× 75). The indusium is here a direct continuation of the marginal growth, and the flattened receptacle and sporangia arise from the lower surface of the leaf.

imposed character biologically advantageous, and conducted without restriction of time.

(ii) There is, however, another element in the evolutionary

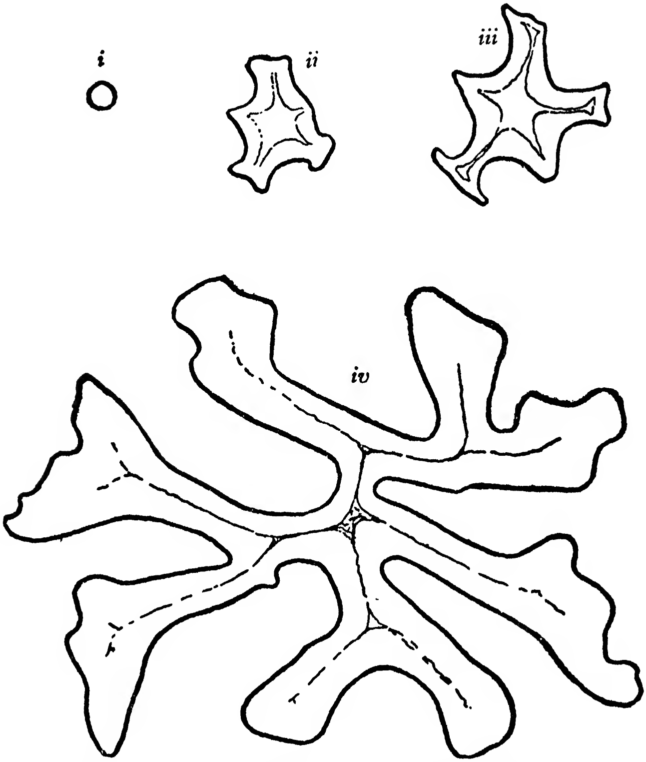


Fig. 20.—Outlines of the xylem of steles of related primitive Ferns, all drawn to the same scale (× 5)

i, *Botryopteris cylindrica*; ii, *Ankyropteris Grayi*; iii, *Ankyropteris Grayi*, a larger specimen; iv, *Asterochlæna laxa*. The elaborateness of outline, and the depth of the fluting, increase with the greater size.

problem which seems hitherto to have received insufficient attention, at least on the botanical side, viz. *the incidence of limiting factors*. This may in itself lead to the establishment of heritable characters such as have been widely used in classification. The initiative to develop brings the individual up

against one or more such limiting factors. The effect is very obviously seen in ferns in relation to increasing size of the conducting tracts. Since under suitable surface-control these supply material to the tissues that they traverse, and since all supply from them is a function of surface, the question of proportion of surface to bulk in the conducting tracts is a critical one. But as the size increases, supposing the original form of the conical stele to be maintained, the bulk of it will vary as the cube of the linear dimensions, while the surface varies only as the square. Consequently a critical point will always be coming nearer, and will ultimately be reached, where the surface-area will be functionally insufficient. As a matter of fact all ferns begin their development with a solid cylindrical conducting stele in the stem; it enlarges upwards in a gently conical form as the plant produces successively larger leaves. In the absence of any secondary thickening each plant is thus constantly approaching that limit of size when further development would be functionally impracticable. The difficulty can be overcome by change of the form of the stelar column. Any change from the cylinder will give an increase in proportion of surface to bulk. Such a change is illustrated by comparison of sections of the stele in allied fossil stems of different sizes, all drawn to the same scale (fig. 20). The smallest is simply cylindrical; the largest has the most complex outline. It is noteworthy that, in the largest of all, the rays of the star are independent, in position and in number, of the insertions of the relatively small leaf-traces: hence the peculiar fluting cannot be ascribed to that cause. The change certainly does result in an increase in proportion of surface to bulk, beyond what the proportion would have been if enlargement went along with a simple cylindrical form. Results similar in principle though different in detail may be seen in all the larger modern ferns. Though other factors may also be contributory to the final result, increase in their size is regularly accompanied by increasing elaboration in the outline of their conducting tracts. This may even be directly illustrated by successive sections taken from the same individual fern-

stem, as it enlarges from the base upwards. Such a series, taken from a fern allied to the native bracken, shows how the larger the plant grows the more complicated does the outline of its vascular system become; and thus the proportion of surface to bulk tends to be maintained (fig. 8, p. 182). It will be unnecessary here to follow the structural points further; it must suffice to say that similar reactions, though differing in detail, are seen in many distinct families of ferns. The general effect is decentralization and disintegration of the vascular tracts. Analogous disintegrations appear also in the stems of *Selaginella* and *Equisetum*, in Palm-roots, and in other plants in which secondary thickening does not step in. Such varied examples show that the principle is of wide application.

Now here we find morphological features, which have often been used for systematic purposes and are found within limits to be stable, related to all appearance causally with the limiting factor of size. Such morphological features have indeed become hereditary, though subject to variability in detail. A solenostelic species, or genus, such as *Loxsoma*, is as a rule solenostelic; a polycyclic type, such as *Matonia*, is constantly polycyclic when adult, though the larger but allied *Dipteris* may be only monocyclic. Every sporeling of a solenostelic, or dictyostelic or polystelic fern, though protostelic when young, assumes its characteristic features in the larger adult parts of its stem. On the other hand, comparison shows that these complications are not directly functions of size alone; for some types though large retain a less complicated structure, while others though smaller have their system highly disintegrated (fig. 9, p. 183). But in all the relation between elaboration of form and the limiting factor of size may be clearly traced, though its effect is seen in varying degree in different species, genera, and families.

How then are we to regard such hereditary features as these —of change of soral position as a means of protection, and of elaboration of the conducting tracts in relation to size in the absence of cambial increase—from the point of view of descent, and of the question of inheritance of acquired characters? We

see that the marginal position rules in certain large phyla of ferns, and probably was general in the first instance for them all. We see sometimes a slight deflection of a marginal sorus downwards in the individual development (*Dicksonia*, *Pteridium*); that deflection, obviously protective, is more marked in related types (*Dennstædtia*, *Pæsia*); while in others, again related, the sorus arises superficially (*Hypolepis*, *Pteris*). Do not these two parallel series suggest very strongly that there has been an inheritance of a character that is adaptive, acquired in increasing intensity in two successions of individual lives? Or again, in the case of increasing size and progressive elaboration of the vascular tracts which is now a feature that is hereditary, does it not appear that the incidence of increasing size has first imposed decentralization and elaboration of the conducting tracts upon the individual life, and that it has now become an inherited character? It would seem a natural interpretation of the facts that the characters of soral deflection or of vascular elaboration, acquired by direct impress upon a succession of individual lives, should have been imposed hereditarily upon each race. Naturally the reply may be made that probably mutations favourable to the perpetuation of the imposed character may have made that character permanent. If we grant that, do we not thereby simply admit that the distinction between fluctuating variations and mutations is not absolute? In other words, that fluctuating variations repeatedly imposed upon successive generations are liable to become mutations? It is difficult to see any other rational explanation of the wide-reaching facts of homoplastic adaptation, such as are shown with exceptional profusion in the ancient class of the Ferns, and are evident in plants at large.

Mnemic Theory of Semon and Sir F. Darwin

This conclusion is, however, directly opposed to the opinions of the followers of Weismann, whose chief tenet was that the characters acquired during the individual life are not heritable. A very fair and philosophical balance of the case of Weismann's theory as against the Mnemic theory of Semon,

with a definite conclusion in favour of the latter, is to be found in the address of Sir Francis Darwin as President of the British Association in Dublin, in 1908. The Mnemic theory proceeds on the conception that, as a consequence of stimulus imposed by the conditions of life, a record or engram is impressed on the organism. Sometimes the engram may be recognized only functionally; and Sir Francis Darwin illustrates this by his experiment in imposing a rhythmic reaction to periodic stimulus, which he found to be continued periodically after the stimulus itself had been removed. He stated his own view for plants thus: " In a plant the ectoplasm may be compared to the sense-organ of the cell, and the primary excitation of the cell will be a change in the ectoplasm; but since cells are connected by ectoplasmic threads, the primary excitation will spread and produce in other cells a faint copy of the engram impressed on the somatic cells originally stimulated." This is a statement in terms of physiology. But Sir Francis Darwin remarks further: " As I have attempted to show, morphological changes are reactions to stimulation of the same kind as these temporary changes. It is indeed from the morphological reactions of living things that the most striking cases of habit . . . are to be found."

It is in the nucleus that the secret of the ontogenetic rhythm resides. Semon assumes that when a new character appears in the body of an organism a new engram is added to the nuclei of the part affected; and that further disturbance tends to spread to all the nuclei of the body, including those of the germ-cells, to produce in them the same change. But this can only be made efficient by prolonged action. He lays great stress upon the slowness of the process of building up efficient engrams in the germ-cells. But the direct experiments by which the theory of Weismann has hitherto been tested are believed by his adherents to refute the idea of the inheritance of acquired characters. So far they have given indecisive or negative results, and it has already been admitted that the direct experimental evidence of inheritance is insufficient. But all those experiments range within narrow limits of time. If the structural record of

experience is slow, as there is reason to believe probable, this negative result from current experiments might have been anticipated. If, however, reference be made to a sequence of events conducted with the latitude of geological time, and the effect appears to be positive, it would seem right to give such positive conclusions precedence over the negative evidence of experiments limited within a brief period. This is the interest which is presented by the phyletic facts relating to the ferns, and especially to the progressive disintegration of their originally protostelic vascular systems; and to the phyletic slide of their sori, originally marginal, to the lower surface of the leaves. Many other progressions in ferns run more or less parallel with these, and in particular the general advance from a more complex to a simpler cellular construction, which finally receives its numerical expression in the reduced output of spores from the individual sporangium as their evolution has proceeded.

Dr. Bateson has remarked that henceforth the study of evolution is in the hands of the cytologists in conjunction with the experimental breeder.[1] While we may heartily endorse the importance to be attached to the work of cytologists and breeders, it is impossible to overlook the arguments of comparative morphology, enriched as they now are by the addition of positive facts from palæontology which, like Pandora's box, is yielding so rapidly new data with hope underlying them all. The cytologist and the breeder deal only with present-day facts, and such generalizations as may be based on them. The morphologist illuminates their problem by the light of the actual achievements of the past, disposed with some degree of historical order according to the palæontological record. He is thus in a better position than they to advance arguments that help us to visualize adaptation as having been operative through long periods of time. But though there may thus have been actually some secular establishment of new inherited features that are adaptive, that need not be held as exhausting the infinitely varied problem of evolution.

[1] *Nature*, May 3 and 10, 1924.

Its effect should rather be to relax that statement of a rigid negative which, to many botanists, appears as a serious blot upon the generalizations of Weismann.

To botanists the sharp antithesis between somatic cells and germ cells in respect of their receptivity for the impress of characters seems inherently improbable for plants. Both are cells of common origin in the plant-body. A comparative study of many lines of descent of primitive plants, such as the green or brown algæ, suggests that zoospores and gametes were originally alike in origin and structure; the latter being probably specialized forms of zoospores, that is, of somatic cells. In the higher plants the distinction between somatic and germ cells cannot be drawn even by the most exact analysis till a late stage of development has been reached, while any somatic cell may be active in regeneration, and so ultimately produce germ cells. Such structural facts from plants give no support to the functional antithesis stressed so strongly in respect of the germ cells of animals. Observation certainly does indicate that there is a difference on the point of receptiveness of impressions between somatic cells and germ cells. The commonness of fluctuating variations, and the extreme sensitiveness of adjustment of developing plants to their environment proves how readily the somatic cell is influenced. The difficulty of producing evidence of inheritance of acquired characters in itself indicates the resistance of germ cells to the reception of engrams. But there is no justification for holding that difference as absolute. The prevalence of adaptation, and its frequent homoplastic origin, together with the arguments of comparative morphology, checked and supported by palæontology, clearly point to the propriety of a position of suspended judgment as to the non-inheritance of acquired characters. The facts derived from Ferns certainly suggest the acceptance of some form of Mnemic theory as a working hypothesis for plants, until a final decision be obtained. Moreover this attitude to the problem seems more likely to produce that decision than the passive acceptance of a rigid negative.

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CHAPTER VI

Zoology

History of the Term "Evolution"

The word "evolution" is a Latin one and means literally "unrolling"; it was originally applied to the opening out of the bud into the flower or into the perfect shoot. In the sixteenth and seventeenth centuries we find it anglicized and used to denote the growth of all kinds of germs, both animal and vegetable: it was even employed metaphorically to describe the history of a people, &c. In the early part of the eighteenth century a theory of animal development was put forward by certain anatomists which was called "the theory of evolution". According to this view all the organs of the adult animal were already present in the egg, but were so small as to be indiscernible, and the process of development consisted in making them apparent, in a word of "unrolling" them. To this was opposed the theory of "epigenesis", according to which the embryo consisted of sheets of undifferentiated tissue out of which the adult organs were developed by growth of different degrees of intensity in different parts. The anatomists divided themselves into opposite schools who adopted the titles of evolutionists and epigeneticists, and a lively controversy was waged between them for half a century—a controversy which, with the gradual improvement of microscopic methods, was decided in favour of the epigeneticists.

The name evolution was chosen by Herbert Spencer to denote his grandiose hypothesis, which was designed to afford an explanation of all that was going on in the Universe from

the movements of stars to the development of animals and plants from simpler forms. This hypothesis was an attempted fusion of the nebular theory of Laplace with the theory of the derivation of existing animals and plants from simpler ancestors, which had been propounded by Charles Darwin. Darwin did not himself use the word "evolution"; he called his theory "the origin of species by means of natural selection or the preservation of favoured races in the struggle for life"; and this theory included the assumption that many existing species had arisen from a common ancestor. Herbert Spencer's attempt to unify all the phenomena of the Universe on the basis of the laws of mechanics has failed, and passed into oblivion, as all such attempts to construct an edifice of theory on an unsound basis of facts are bound to do; but the name "evolution" which he applied to Darwin's theory has remained, and this theory has revivified the science of zoology and has become its very life-blood to-day. Apart from it zoology becomes reduced to a descriptive catalogue of the various kinds of animals, an enormous mass of details without any principle to unify them.

It is the object of this chapter to explain clearly what Darwin meant by his theory, to give an outline of the evidence which he adduced in favour of it, and then to examine how far that evidence is still valid; and if not, what modifications, if any, must be made in the theory in the light of our present knowledge. Finally we shall sketch how the theory illumines the past history of animals on the globe, and how and why the existing tribes of animals came into being.

The Darwinian Theory: Origin of Species

Darwin takes as his starting-point the observed qualities of animals and plants as we see them living to-day. From this basis he endeavours to reason backwards to what their condition has been in past times. In a word Darwin takes life for granted, and has nothing to say about the supposititious origin of living things from dead matter, or of evolution as "an integration of matter with a diminution of motion" It is

true, as Darwin himself points out, that many observers before him had been impressed by the close similarities between allied species of animals and plants, and had reached the conclusion that this similarity was evidence of blood relationship, in a word, of community of descent. But the weak point in previous theories had been that they did not show that evolution must inevitably result from what we can observe going on under our eyes to-day. Their opponents urged that it was universal experience that like begat like, but that if evolution were really going on, like must somehow give rise to what was unlike. Darwin claimed that his theory enabled us to surmount this obstacle; and he succeeded in convincing the scientific world of his day that he was right, and so the enormous influence of his theory on contemporary thought is explained.

When we examine the infinitely varied assemblage of animals which we see in the world around us, we find that they can be sorted into groups, each of which consists of individuals which differ from one another only by the marks indicative of age and sex, and which mate with one another freely when given the opportunity. These groups are termed *species*: and they exhibit all degrees of likeness and unlikeness to one another. Those which resemble each other most are grouped together in the same *genus*: similar genera are placed in one *family*: families are collected into *orders*, orders into *classes*, and finally classes into *phyla*, which may be regarded as the primary divisions of the animal kingdom. Now genera, families, and orders are merely names given to convenient bundles of species, and taste as to matters of convenience differs widely amongst naturalists. There are in fact "lumpers" who are inclined to include very many species in one genus, and "splitters" who break up the old genera into much smaller groups. Thus for instance most of our visitors to the seashore are acquainted with the common sea-urchin, which in quiet inlets, such as the sea lochs of Scotland, may be found clinging to the rocks laid bare at low spring tides. There are two marked varieties of this urchin, viz. a large reddish purple one about the size of an orange, and a small green one about

the size of a horse-chestnut. The first is termed *Echinus esculentus* and the second *Echinus miliaris*. Thus it will be observed that the British zoologists place them both in the genus Echinus. But the Danish zoologist Dr. Mortensen restricts the genus Echinus to *Echinus esculentus* and some very closely allied species, whilst *Echinus miliaris* is placed in another genus, viz. Parechinus.

Under these circumstances it will be seen that the real problem to be faced is the origin of species—and this is why Darwin chose this phrase as the title of his great book. Whatever the cause may be which has differentiated one species from another, it is quite evident that the continued action of the same cause will account for the separation of one group of species which make up a genus from those which constitute another genus, and for the separation of genera within a family and of families within an order and orders within classes.

Species differ from one another to an enormous degree in the extent of territory which they inhabit; some, like certain land-shells, are confined to a single valley in one of the Pacific islands such as Tahiti; others, as for instance certain birds, range over the entire breadth of the continent of Asia.

Now in Darwin's time all naturalists recognized the fact that wide-ranging species were slightly different in different parts of the region which they inhabited, and these local groups were termed *varieties*: they are now more usually called *local races*. All Darwin's opponents admitted that these local races had been derived from the same mother species, and if questioned how this had occurred would doubtless have replied, that the different climatic conditions in different places had produced different results on the local population of the species. Darwin then showed that in many cases it was impossible to say whether a certain form was a local race or a species; one set of systematists would class it in one category, another in the other category: so that it was inherently improbable that if local races were produced by the reaction of animals to climate, species were made by supernatural acts of creation. He next showed that the domestic races of pigeon differed

from one another in shape and details of structure far more than did genera of wild birds, and yet that all of them had been derived from the common rock pigeon *Columba livia*, for all of them agreed with *Columba livia* in nesting habits and voice and all were fertile when crossed with it. He found that breeders, when they were endeavouring to "improve the breed", carefully selected those members of their stock for propagation which showed the "points" which they wished to emphasize in strongest degree. Then he pointed out that every species of animal and plant produced so many young, that if all survived each species in a few years would sweep over the entire earth and crush out every other kind of life. This is a fact which few realize, because in most cases we do not see or at any rate notice the enormous destruction of young which goes on before our eyes. A single example will give some idea of its magnitude. The common thrush begins to produce eggs when it is one year old and its average length of life is about ten years. Every year a pair of thrushes will rear two broods, each consisting of about four nestlings. Starting from the offspring of a single pair we find that if all survived and mated, at the end of the tenth year, that is at the completion of the life cycle of the parents, they would have produced a population of $19\frac{1}{2}$ millions. These in another ten years would grow to nearly 200 billions, and at the end of thirty years to about 1200 trillions. There would not be room for more than the $\frac{1}{150000}$ part of such an army of thrushes on the entire surface of the earth even if all stood side by side touching each other. Consequently only a very small proportion of the thrushes born will survive, and those that do survive will be those that are most successful in solving the two main problems of life, viz. how to obtain food and how to escape enemies. This survival of the few was called by Darwin *natural selection*; he metaphorically personified Nature and pictured Her as proceeding in the same manner as the artificial breeder, i.e. picking out those individuals which by their peculiarities were best *fitted to survive*. He assumed that is to say that the survivors owed their good

fortune to their possession of individual traits which enabled them to escape pursuit or to find food rather better than their fellows. The twofold struggle to accomplish these objects Darwin called *the struggle for existence*.

The Darwinian Theory: Natural Selection, Sexual Selection

Let us give some simple examples of this struggle. Most visitors to our coast have seen the gannet or solan goose. This magnificent bird, recognizable by its great expanse of white wings each crossed by a prominent black bar, gains its living by diving into the sea for fish. This dive is quite characteristic, and at once enables the bird to be discriminated from the larger gulls which it somewhat resembles when seen at a distance. The gulls likewise live on fish, but they scoop their prey from the surface of the water by a slanting rush. The gannet, on the other hand, transfixes the fish with its long pointed bill; it is able to perceive the prey even when this is at a considerable depth, and it precipitates itself upon the fish from a height of fifty to sixty feet by a vertical dive which may be called " a dead man's plunge ". Now when a storm supervenes and the surface is disturbed by waves of all kinds, the gannet is unable to perceive its prey: just as during the late war our aeroplanes under similar circumstances failed to discover the German submarines. When this occurs the only resource of the gannet is to fly as swiftly as possible beyond the range of the storm until it reaches calmer water. It sometimes has to fly fifty miles before it accomplishes this object, and the weaker birds become exhausted and die on the way: only the stronger reach the goal of peace and plenty, and these alone survive and so hand on their superior strength to posterity. These then are " selected " by Nature. Again, when a herd of zebra or antelopes are suddenly menaced by an attack by lions, it has been recorded again and again that the attackers invariably choose the weaker quarry, and so the weakling members of the herd which tend to lag behind are caught.

But besides solving the problems of getting food and of eluding enemies, the successful animal must find a mate. This quest is always undertaken by the male; and the struggle to accomplish it leads to the success of the most vigorous and attractive male; a result which Darwin called *sexual selection.* Sexual selection was supposed to depend on the choice of the female, who yielded herself to the most pleasing partner available. It is an extraordinary fact that outward and conspicuous differences between the sexes are found throughout the animal kingdom till we reach animals as lowly as the worms; and these differences were assumed by Darwin to depend on the idiosyncrasies of female choice. There is no doubt an element of truth in this theory, but it did not command nearly as wide a measure of assent as the theory of natural selection, which is accepted by all. Wallace, who arrived at the same theory of evolution as Darwin simultaneously with him, rejected the idea of sexual selection.

Let us take a few examples of sexual differences, beginning with those that are most familiar. Thus all are aware that the male deer or stag is provided with a magnificent pair of branching horns or antlers, whilst the female deer or doe is devoid of them. Again amongst our domestic fowls the cock is distinguished by his erect comb, his spurs, and his long tail which the female does not possess, and in singing birds it is usually only the male who sings. If we descend lower in the scale we find that the male wrasse—a fish about the size of a large perch—assumes bright and variegated skin colours during the breeding season and persistently chases the female. It is still more remarkable to find similar differences distinguishing the sexes in insects. In many tropical species of butterflies the male is brightly and conspicuously coloured with a pattern of yellow and black, whilst the female is of a dull brownish colour. Even amongst the worms which live at the bottom of the sea and rise to the top to mate we find that the male Syllis is so different from the female that the two were formerly placed in different genera.

Now if we take the case of the deer, it is well known to

gamekeepers that during the autumn, when the breeding season begins, the male deer fight furiously together and that the strongest male eventually drives off his competitors and remains the sole lord of a herd of does of whose offspring he is the father. In this contest he uses his antlers, and so the best antlered male will be the victor and will transmit his qualities to his posterity. But as Wallace points out, the very same vigour and weapons which aid him in this struggle will also assist him in the fight against wolves, and so the theory of sexual selection becomes redundant. The case, however, is not so simple when we descend to the level of birds. It is true that one cock will fight with another for the possession of hens; but amongst black grouse and allied species, it is known that the cocks will strut up and down on a bare spot in the forest and display their fine feathers to the hens, so that here a certain measure of female choice cannot be denied. If, however, we take the case of the wrasse, there is no evidence that the female exercises any choice at all; the bright colours of the male appear to be a sort of by-product of his vigour. This has been definitely proved to be the case with the minnow. The cells containing colour are the same in both sexes, but those of the male are excited to expand by his sexual secretions. Still less is it credible that the female butterfly compares the colours of her would-be partners and chooses the most gaily coloured; nor does anyone seriously suggest that the female Syllis selects the male one. Perhaps Mr. Julian Huxley has given us the best

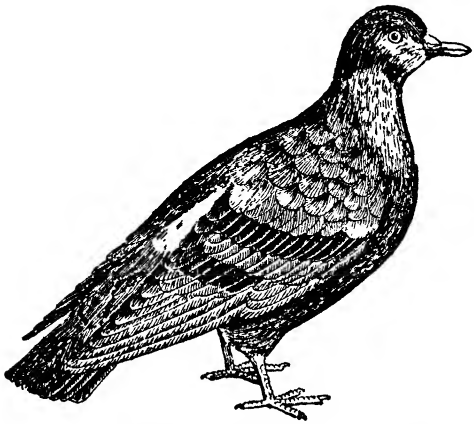

Fig. 1.—The Wild Rock-pigeon (*Columba livia*)

solution of the riddle, when he points out that in mating male desire first becomes active, whilst female desire at first lies dormant and is difficult to arouse; and it is the male who by his vigour, voice, and display first succeeds in arousing this desire that is successful. The male colours and outgrowths are thus the secondary result of the effect of his "maleness" on structures which he shares with the female.

Fig. 2.—The Pouter Pigeon

So far as we have given an outline of the Darwinian theory it will be seen that natural selection separates out the most vigorous members of a species and kills off the weaker ones. This would account for the progressive improvement of a species as time went on, but it would not explain how the descendants of one species became differentiated into two different stocks which ultimately became two distinct species, and unless this explanation is forthcoming, the theory of evolution fails to account for the facts.

Now Darwin points out that, working on the same stock, breeders of pigeons succeed in producing widely different birds according to the " points " for which they bred—that is according to the type of individual which they selected for mating.

If we contrast for instance the pouter pigeon, with its enormously swollen crop and long powerful legs covered with feathers, with the barb, which has a diminutive beak and small, feeble, short legs, and ask, what caused the differences between them, Darwin would say the different preferences of different breeders. If one set of fanciers always selected slight devia-

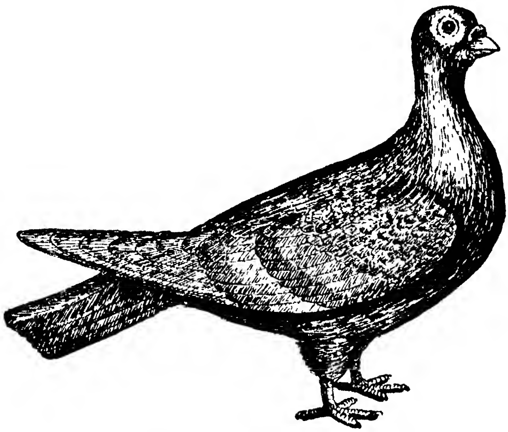

Fig. 3.—The Barb Pigeon

tions tending in one direction and others those tending in a different direction, eventually two totally different types of bird would be produced. Now Darwin assumed that a similar diverse selection occurred in Nature. If a species occupied a large area the " fitness to survive " might be different in two parts of it, and so individuals showing different peculiarities might be selected in the two areas, and if intercrossing was prevented two species might eventually be formed out of one.

The Darwinian Theory: Origin of Interspecific Sterility

When defining the word species, we emphasized the fact that all the individuals composing a species mate readily

with each other, but we should have added that it is assumed that they will refuse to do so with members of other species. When crossing between two species is artificially brought about, it usually happens that either no offspring result or that those which do result (hybrids) are sterile. Now it is obviously this sterility which keeps distinct two allied species whose territories border on each other; and it is quite as important in its way as the assumed different types of selection in different places, in splitting up a single species into two. Of this sterility Darwin could give no clear explanation; he showed, however, that amongst certain plants it could appear within the limits of a species. The most striking case is that of the common primrose. This well-known flower appears in two varieties termed respectively the "pin" flower and the "thrum" flower. The pin flower has a prominent stigma protruding from the mouth of the corolla, whilst the stamens are short and do not reach more than half-way up the tube of the corolla. In the thrum flower, on the other hand, the stigma only reaches half-way up the tube, whilst the stamens are long and protrude from the mouth of the corolla. If now pollen be taken from long stamens in a thrum flower and placed on the stigma in a pin flower, many good seeds will be produced; and if pollen be taken from the short stamens in a pin flower and transferred to the short stigma in a thrum flower the same result will be achieved; but pollen from the short stamens in one pin flower placed on the long stigma of another pin flower, or pollen from the long stamens in a thrum flower transferred to the short stigma of another thrum flower yields few or no seeds.

Darwin concludes that sterility between species is a sort of by-product of increasing divergence of constitution, and indeed until this day no better explanation of it has been put forward. This view has been confirmed by the recent experiment of Goldschmidt in crossing the local races of the Gipsy Moth *Lymantria dispar*. When widely separated races are crossed, sterile individuals are often produced of mixed sexual characters, and it becomes impossible to propagate the hybrid race.

This then is the theory of evolution as Darwin propounded it, and we must now examine it critically in order to see if its foundations are sound. It will be at once observed that its full development has introduced quite other assumptions than those underlying the simple illustrations which we gave of it at first. In dealing with gannets we pointed out that natural selection picked out the most vigorous individuals and destroyed the weaklings, so that those which survived were those which did most strongly and well that which the species as a whole was accustomed to do. But Darwin assumes that in different regions different types of individuals might be "selected", and that the causes of their selection were chance correspondences between the needs of the environment and random variations, which were always appearing and which were in all directions. If this is really so, then as Dr. Bateson has said "variation is evolution". Variation might be compared to a thickly growing tree and natural selection to the knife which cuts off all but the most promising shoots, and the search for the causes of evolution resolves itself into the inquiry about the causes and nature of variation.

The Darwinian Theory: Origin of Variations, The Inheritance of the Effects of Use and Disuse

Now Darwin assumed that the minute differences which distinguish members of the same brood or litter from one another were inheritable, and not only that they were inheritable, but that each would in turn give rise to other variations in the same direction as that in which each had originally deviated from the parent species. This assumption was adopted with enthusiasm by his followers: by means of it it seemed at first that any possible change could be accounted for, and it was not seriously questioned until about 1903. Nevertheless Darwin perceived that there were phenomena which were difficult to explain as the result of the survival of individuals showing favourable variations. Cave animals were known to be allied closely to normal species which lived outside: these cave species living in the dark were either devoid of

eyes altogether or had their eyes reduced to vestiges. How did this come about? Could it be seriously maintained that an animal which did not use its eyes at all would be more likely to survive if it had smaller eyes than its neighbours? Darwin could not reconcile himself to such an absurd proposition. It is a matter of common experience that an organ which is not used from childhood fails to grow and develop like one of which full use has been made. Hence Darwin assumed that the eyes of animals living in darkness failed to grow to their proper size owing to lack of use, and *that this diminution in size was inheritable, in a word that the effects of disuse were inherited.* But if this were so, then it must be admitted that increased size due to use was also inheritable, and herein lay at any rate two great causes of variations. But besides these Darwin attributed to changes in climate the power of upsetting, so to speak, the hereditary constitution of animals. This disturbance he thought produced an indefinite variability in all directions, and so gave to natural selection its chance of producing any change that circumstances called for.

But Darwin's followers were not so wise or broadminded as he himself was. Having persuaded themselves on theoretical grounds that it was impossible that changes produced in the body of an animal could cause corresponding changes in the germ-cell, and hence that nothing that happened to the animal could have an effect on the development of the young, they felt bound to account for the blind cave animal in some other way, and the explanations they put forward were amazing. Of these the best known is the so-called "panmixia" theory of Weismann. Weismann assumed that as soon as an organ became useless to its possessor, then it made no difference to the individual's survival whether it was well developed or not, and so beasts with poorly developed eyes were preserved: and these crossing with the rest lowered the general standard of eye-development in the population. But Weismann overlooked the fact that on the theory of indefinite variability, variations in the direction of over-development should be as frequent as those in the direction of under-development, so

that if both were preserved, the eyes would reach a fixed level of development below which they could not be depressed by natural selection. It was then suggested that the nourishment diverted to the useless organ was a handicap to its possessor, who was thereby debarred from competing successfully with a neighbour possessing a similar organ of smaller size: but if one seriously considered what this implied it became apparent that it was not less untenable than " panmixia ". When an organ had reached a small size, could it be supposed that the diversion of nourishment necessary to maintain it at that size was going to determine the death of its possessor when in competition with an animal in which the size of the organ was slightly diminished?

Pure Line Experiments

But the whole theory of the constant abundant production of random variations in all directions, which underlies the idea of evolution by natural selection, received a rude shock by what are called the " pure line " investigations of Johannsen in 1903. These were carried out with a bean (*Phaseolus*, the scarlet runner), but they were confirmed by researches on animals undertaken by Agar and Jennings. A pure line may be briefly defined as a group of offspring derived from a single parent, so that no question of the interaction of maternal and paternal heredities arises. In the case of flowering plants this is easily arranged by fertilizing the stigma of a flower with its own pollen. Johannsen raised a bean plant by sowing a bean of a carefully ascertained weight. When it flowered he self-fertilized all the flowers, and collected the resulting beans, all of which were carefully weighed. He then took the lightest beans and sowed them, self-fertilizing the flowers and collecting the crop; and he sowed separately the heavier beans, treating them in the same way. The crop produced by each bean was kept separate from that produced by every other bean. When these crops were examined it was found that the crops produced by the lighter beans were on the average quite as heavy as those produced by the heavier beans; that in fact *selection had no influence whatever in in-*

creasing or diminishing the weight of the beans. There exist, however, different " strains " or " races " of these beans, some producing on the average heavier beans than the others, and if members of one race are crossed with those of another an irregular distribution of maternal and paternal qualities results. Selection amongst such a population, either for weight or for lightness, is apparently effective, because we are in fact eliminating all the individuals which do not show one set of qualities (maternal or paternal) in its purity, but when that elimination

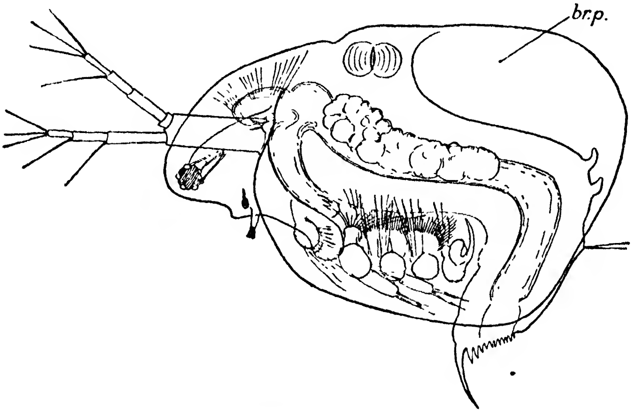

Fig. 4.—Simocephalus seen from the side. *br.p.*, brood pouch.

has been completely effected further selection has no influence whatever.

Agar's work was done on a small water-flea (*Simocephalus*) which carries its young in a brood pouch between its shell and its back. The development of the eggs during summer is very rapid, and the young at birth resemble the parent. If they are well supplied with food they grow up quickly and in four moults attain adult size. These eggs develop " parthenogenetically ", i.e. without being fertilized. Agar measured the length of the shell (or "carapace") from its front extremity to its hinder end. He found, in the result, that there were several strains of Simocephalus characterized

by having carapaces of different average lengths, and that if he isolated a single female, and attended only to her offspring, these offspring differed from one another in the length of their carapaces; but that a female of such a brood with a longer carapace produced daughters with carapaces no longer than those produced by a female with a shorter carapace; in fact in Agar's experiments offspring with slightly longer carapaces were produced by females with short carapaces.

Jennings worked at the well-known Slipper Animalcule or Paramœcium. This animal is found swimming in infusions of hay or other decomposing materials, at a certain stage of decomposition. It is a "protist", that is to say its body is

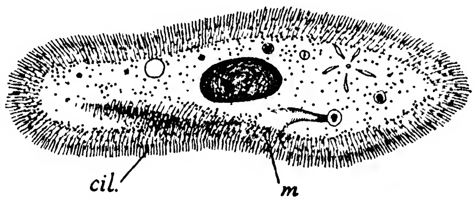

Fig. 5.—The Slipper Animalcule (Paramœcium) seen from the side
cil., cilia. *m.*, mouth.

not divided into cells like those of the higher animals, in fact in many respects it may be likened to a single cell of one of the higher animals. It is shaped like a bedroom slipper with a flat heel, and it propels itself by means of vibratile hairs or cilia. It reproduces itself by dividing into two across the middle: each half then grows till it reaches the size of the adult.

Jennings isolated a single Paramœcium and investigated the lengths of the offspring produced by this continual process of division. He found that they varied in length, but that if he selected a shorter specimen and raised a culture from it, the average of length amongst the individuals composing this culture was just the same as that average in a culture raised from an isolated longer individual. Here again selection is shown to be utterly ineffective in bringing about change.

When it is remembered that it would be hardly possible to

select three living beings more widely separated from one another in structure and mode of life than a flowering plant, a water-flea, and a protist, and that all three give the same answer when examined for this indefinite inheritable variability which was postulated by Darwin and his followers, we can only conclude that this variability does not exist.

Mutations or Sports: Mendel's Laws

There is, however, another type of variability which was well known to Darwin and to breeders long before him. This type consists in the sudden appearance of "sports", that is of individuals which show marked deviations from the normal type. These sports are relatively rare, but when they occur and are mated with their like, they transmit their peculiarities very strongly to posterity. The idea that natural selection seized on these sports and used them for the purpose of producing new species, had occurred to many naturalists and was considered by Darwin. Darwin, however, came to the conclusion that sports occurred far too rarely to have played any part in the process. The chance in Nature of a single sport mating with its like would be infinitesimally small, and if it mated with a normal individual and the offspring of this union in turn paired with other normal individuals, its peculiar characteristics would be so toned down in several generations that they would fail to count at all. But the doctrine that sports form the raw material of evolution has been revived since Darwin's time with great force, and it is firmly held by a large number of zoologists at the present day. We must therefore examine it in rather greater detail.

In order to fix our ideas, let us take one or two instances of sports. One of the most striking of these is the seven-toed cat. In this animal there is a sixth toe beyond the little toe and the thumb is cleft into two. Not only does a seven-toed cat reproduce its like when it is mated with another seven-toed cat, but even when it is paired with a normal cat most of the litter are likely to show the abnormality.

Another sport is the white mouse. In this little animal

all pigment is absent from the skin. The eyes, it is true, are pink, but this is due to the blood-vessels of the iris and retina shining through the transparent tissues. The white mouse paired with its like produces nothing but white mice. If it be crossed with a wild mouse, the offspring are all grey like their wild parent, but if these offspring be crossed with each other and a comparatively numerous progeny be reared, about one-quarter of the next generation will be white.

These two examples which we have cited illustrate one of the most striking features of sports, viz. that when they are

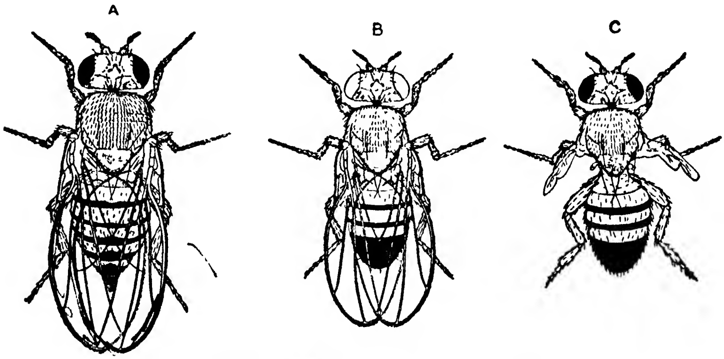

Fig. 6.—The Banana Fly (*Drosophila melanogaster*)

A, the normal type. B, a " sport " with white eyes and shortened wings. C, a " sport " with normal eyes and shrivelled vestiges of wings.

crossed with the type the first generation is not usually intermediate in character but resembles either the father or the mother—in a word either the father's or the mother's heredity is *dominant*. When the second generation (usually known by the symbol F2) are reared, about three-quarters of them resemble the "dominant" grandparent, whilst one-quarter resemble that grandparent whose peculiarities disappeared in the first generation; this ancestor is usually termed the *recessive* ancestor. If the recessive members of the second generation be bred with their like they will breed true, that is to say that however long the experiment be carried on and however many genera-

tions be reared nothing but recessive characters will appear. Of the dominant members of the second generation, however, only one-third will breed true; the rest will give mixed families of dominants and recessives.

These modes of the splitting up of the second and subsequent generations and of the predominance of the characters of one parent in the first generation are usually called the "Mendelian rules", because they were first discovered by Gregor Mendel, an Augustinian monk who grew pea plants in his cloister gardens at Brünn in Moravia in 1850. They have been shown to be true of animals by many workers, of whom the most conspicuous is Professor Morgan of New York, who with his pupils has reared millions of the banana-fly *Drosophila melanogaster*.

Now those who uphold the "sport" or as it is more often termed the "mutation" hypothesis of evolution argue thus: if a sport appears in Nature under wild conditions *and happens to be advantageous to the species*, it will be preserved by natural selection. It will be either dominant or recessive; if it is the former, with whatever mate it pairs it will impress its peculiar qualities *on all its offspring*, which therefore will all be successful, and a considerable proportion of their offspring will also show the new character so that the novelty will not be diluted to disappearance by intercrossing. If the sport is recessive, though it will be obliterated in the progeny of the first cross it will reappear in the next generation, and since such a small proportion of the progeny survive in any event, the recessives which do appear if they survive will be enough to ensure the continuance of the species.

To this plausible reasoning, however, there are two very great objections. The first of these depends on the rarity of sports, the second on their nature. Mathematicians who have interested themselves in biology tacitly assume that all members of a generation start equally equipped for the battle of life. If on the average only one in a hundred thousand survives and a mutation occurs once in a hundred thousand offspring, then they conclude that the individual showing the mutation

will be the successful one and will thus make sufficient provision for carrying on the race. But this is a travesty of what actually occurs. The greatest destruction of the "unfit" takes place before the mating age is reached: a good deal of this destruction is fortuitous, as when a predaceous fish swallows a mouthful of herring-fry. An animal on its way to maturity runs the gauntlet of different dangers at different stages of life, and unless a variation occurs frequently its possessor will have a vanishingly small chance of surviving so as to reach the mating age at all.

But a deeper objection to regarding "mutations" as the raw material for evolution lies in their nature. All those that have been described and the hereditary qualities of which have been tested are of a pathological character, that is to say in plain English they render their possessors crippled or deformed as compared with the type. They are comparatively common amongst garden plants and domestic animals which live under unnatural conditions; they are exceedingly rare in wild nature, and from their character when they do appear they are certain to render their possessors "unfitted to survive".

Tornier on the Origin of Mutations

Now these facts would lead us to suspect that mutations must owe their origin to a bad environment, and quite recently a good deal of evidence has been collected to show that this is really so, and we shall now give a brief outline of the evidence. It has been collected by a German worker called Tornier. Tornier drew attention to the case of gold-fish. No animals artificially bred exhibit mutations comparable in variety and extent to those shown by the different races of this fish. They are all derived from a small grey carp which is still to be found in the rivers of China, and the Chinese were the original breeders of this fish and have produced all the leading cultivated races of it. The wild ancestor is called *Carassius auratus*: it is a very ordinary fish of a greenish grey colour above verging to a lighter tint beneath. It possesses one dorsal fin and one anal fin, a tail (caudal) fin, and the usual pairs of pectoral (breast)

fins and pelvic (belly) fins. These last are in the primitive position some distance behind the breast fins. The cultivated races differ from the wild type in size, shape, and colour. The colour in the vast majority of cases is the familiar reddish gold tint; from a passage in the Chinese classics, it appears probable that it was the sporadic appearance of this colour about the year 1200 A.D. that first attracted the attention of fish lovers and led to this fish becoming the object of " fancy breeding ". But though most of the races are " gold " in colour, others vary towards a steely white colour (the so-called silver fish),

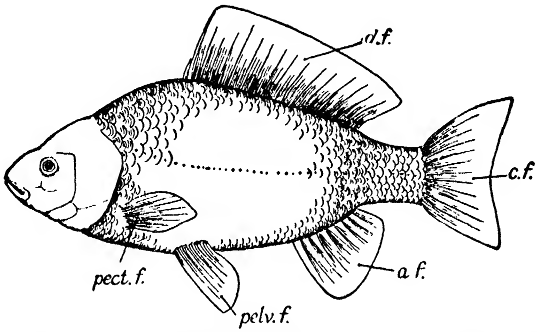

Fig. 7.—*Carassius auratus*, the Wild Ancestor of the Gold-fish, seen from the side

a.f., anal fin. *c.f.*, caudal fin. *d.f.*, dorsal fin. *pect.f.*, pectoral fin. *pelv.f.*, pelvic fin.

whilst still others termed " moors " are so heavily pigmented as to be almost black. Still others, the so-called " tigers ", are mottled with patches of black. So far as shape is concerned, whilst the typical wild fish is of the usual spindle shape, all the cultivated races are shorter, thicker, and more deeply bellied. These aberrancies of form reach their maximum in the so-called Egg-fish and Meteor-fish, which are so short and fat as to be almost globular. Coming now to aberrancies of structure we find that these chiefly affect the head and eyes and the fins. In the "Buffalo-head" and "Lion-head" the skin of the head is raised into bulbous swellings. In the so-called Celestial fish the eyes protrude like telescopes from the side of the head. But the most striking divergences from type

affect the fins. In the Comet-fish the dorsal, anal, and caudal fins are enormously elongated: in the Nymph- or Veil-fish this is also the case, but the edges of the fins are flexible and droop like a lady's veil, and moreover in most of the breeds of Veil-fish the tail fin and the anal fin are doubled, and are represented by two similar fins standing side by side. This is also true of the Celestial Fish. In many cases the dorsal fin is completely absent: the anal fin can also be absent, and finally in the extraordinary Meteor-fish the tail fin is absent.

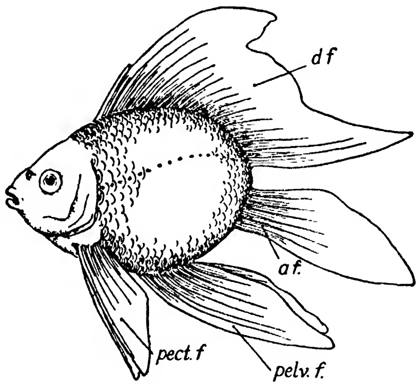

Fig. 8.—The Meteor-fish. A variety of Gold-fish devoid of tail fin

a.f., anal fin. *d.f.*, dorsal fin. *pect.f.*, pectoral fin. *pelv.f.*, pelvic fin.

These races of fish can be propagated and produce a number of offspring which resemble their parents, but some of the offspring tend to revert towards the type: that is to say, they show the peculiar features of the race in lesser degree than did their parents. By selection carried on, however, for two or three generations a strain can be produced in which these reversions are reduced to a minimum.

Now Tornier discovered that the Chinese breeders rear their fish under the most insanitary conditions. In winter they are kept in small earthenware pots ranged by hundreds on shelves in dark and ill-ventilated huts, and in summer they are transferred to small dirty tanks overgrown with

weed. In these tanks they spawn and much of the spawn dies, but amongst the portion that survives monstrosities of all degrees of intensity appear, and the most striking of these are selected as the founders of the fancy breeds. In view of these facts Tornier has put forward the view that all the features in which these breeds depart from the normal type —elongated fins, doubled fins, absence of fins, protruding eyes, puffed skin, and short deep shape—are due to the same cause, viz. the weakening of the vital powers of the embryo

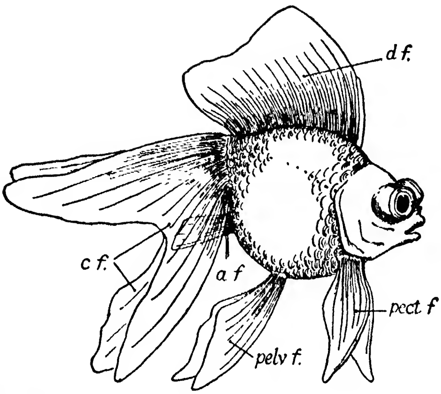

Fig. 9.—The Celestial Fish. A variety of Gold-fish with protruding eyes and doubled tail fin

a.f., anal fin. *c.f.*, caudal fin. *d.f.*, dorsal fin. *pect.f.*, pectoral fin. *pelv.f.*, pelvic fin. Note the double caudal fin.

by the abstraction of the necessary oxygen at an early and critical period of development. This period is the one intervening between fertilization (which in fish occurs after the egg is laid) and the period when the rudiment of the central nervous system is formed in the embryo. We shall employ the term "germ-weakening" to denote this effect. Now the egg of a fish consists of two regions sharply contrasted in their characters: there is an upper or "animal" pole consisting of protoplasm (i.e. living substance) and a lower or "vegetative" pole consisting chiefly of yolk (that is food material). The embryo develops from the animal pole and becomes curled

round the egg, ultimately enveloping the yolky half of the egg, which is eventually digested and absorbed. The still unused yolk, however, causes a bulge in the belly of the young fish termed the yolk sac, and the yolk does not completely disappear until two or three days after the young fish is hatched. The first step in development is an increase in bulk of the egg due principally to the absorption of water: all the parts swell but principally the animal half, which at the same time is rapidly dividing into numerous cells. When, however, the vital energy of the embryo is diminished, this swelling is decreased and the speed of development is slowed down, and the swelling of the yolky half of the egg is proportionately greater. The egg it must be remembered is enclosed in a tight membrane. The swollen yolk crushes the elongating embryo and presses the head upwards and prevents the spine from attaining its full length, and so the short rounded shape of the fancy breeds is explained. At the same time the embryo loses its power of properly "regulating", i.e. controlling, the intake of water, and so all the natural cavities become engorged with water, as for instance the abdominal cavity, the mouth cavity, the gill cavities, and in the last resort the cavities of the eye-balls. When these last-named cavities are stretched the eyes protrude like telescopes. Sometimes when the skeleton of the head undergoes an intense compression the skin covering it is raised into folds (just as is the skin on the face of a bull-dog) and so the peculiarities of the "Lion-head" and "Buffalo-head" are explained. Long fins are explained by the circumstance that the area of skin from which the fin grows is kept on the stretch by the swelling yolk underneath. The normal embryo early executes wriggling movements with its tail; these movements distend the egg membrane and make more room for the expansion of the growing organs. But in the case of the weakened embryo these movements are feeble or absent and the membrane remains tight. The elongating fins impinge against it and become bent over, and so the peculiar drooping "veil-fins" of the Nymph-fish are produced.

Sometimes, however, the area from which the fin has to

grow is compressed by the swelling of the yolk in an adjacent area. When this occurs the fin is reduced in size or disappears altogether (like the dorsal fin in many breeds or the tail-fin in the Meteor-fish). Finally the swelling yolk sometimes becomes forced in between the right and left rudiments which normally join to form the tail-fin and then a doubled tail-fin is produced (fig. 9).

Variations in colour, according to Tornier, are also due to germ-weakening. It is a well-known symptom in certain human diseases (as in Addison's disease) that an overproduction of pigment takes place, leading to an unnatural bronzing of the skin. A similar overproduction causes the dark varieties of gold-fish known as "Moors" and the blotches of pigment on the skin of the "Tigers". But according to Tornier ordinarily when in the weakened egg too much water is absorbed by the yolk, part of the yolk coagulates and becomes indigestible. This insoluble portion is later thrown out by the anus. Later in development, in consequence of this loss the embryo runs short of nutrition and begins to draw on the pigmentary substances embedded in the cell. These become diminished in quantity and in consequence the embryo becomes paler in colour, passing through the whole gamut of colours from grey to orange and eventually to steely white.

Tornier subjected the eggs of newts and toads to loss of oxygen during the early stages of development. This he accomplished by placing them in strong solutions of sugar for limited periods. In the case of the large newt called the Axolotl, which normally keeps its gills throughout life, Tornier secured embryos and young newts which reproduced many of the peculiarities of the fancy breeds of gold-fish. Further, by stabbing the eggs of toads with a fine needle and causing the loss of a considerable quantity of yolk, he succeeded in producing lemon-yellow tadpoles. One of his pupils (Milewski) bred together in good clear water two gold-fish which possessed long fins (the so-called Nymphs). They produced a brood of fry of which only ten per cent reproduced the peculiarities of the parents to their full extent: the remaining ninety

per cent showed a greater or less tendency to revert towards the type of normal gold-fish. Then he obtained a second brood from the same pair under conditions when the water was deprived of a large part of its free oxygen: and of this second brood no less than ninety per cent reproduced the peculiar features of the parents whilst only ten per cent tended to revert towards the normal. Some of the members of this second brood were reared for three years, and then began to show the "telescopic" eye which as we have seen is a feature characteristic of other breeds, but one which was not exhibited by either parent.

Tornier's conclusion is that in the formation of these breeds what is transmitted in heredity is not a special "unit-factor" for a special characteristic such as a lengthened fin, but a definite intensity of germ-weakening together with a tendency for that weakening to be localized in a particular region of the germ. When the weakening is slight only certain organs are affected, but when it is more severe other organs are involved and fresh pathological symptoms make their appearance.

It seems to us that Tornier's observations and experiments have dealt a deadly blow at the whole "mutation" hypothesis of evolution, as well as at that part of Darwin's argument which is based on the comparison of the abnormalities shown by our domestic breeds, and the differences which distinguish natural species of animals. For, as Tornier justly points out, the moment that our eyes become accustomed to recognize the stigmata of germ-weakening, we recognize them wherever we look amongst our domestic animals and cultivated plants. It is true that many of the peculiarities of these breeds are extremely useful to man, but when they are regarded from the point of view of the animal (or plant) itself they can only be deemed pathological monstrosities.

If we take the prize pig with its shortened snout and reduced jaws, and its huge fat body hardly lifted off the ground by its short legs and only able to move in a feeble waddle, and contrast it with the lean wild boar with its lengthened jaws and

powerful tusks, its agile gait and its enormous energy, no shadow of doubt is left in our minds as to which is the weakened type. Of course it may be objected that the egg of a mammal is devoid of yolk, and remains within its mother's body until development is complete and so is not exposed to the influence of water poor in oxygen. The part played by the surrounding water in the case of the egg of the gold-fish is assumed by the mother's blood in the mammalian egg, and this blood when the mother is living under unhealthy conditions (as is the case with most of our domestic animals) is often loaded with toxins and insufficiently supplied with oxygen. There is no yolk to swell it is true, but the embryo is closely invested by a membrane termed the amnion which has to be distended and forced away from the embryo as growth proceeds. When in germ-weakened embryos this membrane clings too closely, all sorts of abnormalities are produced, such as supernumerary fingers in man (due to compression of the growing rudiment of the hand by the amnion), and these abnormalities are inherited. In the case of plants the germ-weakening seems to be brought about by the slow suffocation of the roots in too heavily manured soil. It is a common experience of gardeners that when a wild plant is cultivated it requires about ten years to induce it to "break", that is to throw off varieties, but these varieties once produced can be propagated by seed.

Now if mutations are the outcome and visible signs of an inner germ-weakening, they can have played no part whatever in evolution, for in wild nature they would at once be eliminated by natural selection. But we have already seen that the minute fluctuating variations relied on by Darwin are not inheritable. What then can have been the changes which constitute the material of evolution? Clearly there is only one alternative left to us, and that is the effects of use and disuse.

Weismann's Dogma of the Impossibility of the Inheritability of the Effects of Use and Disuse

Now although Darwin recognized the inheritability of the effects of use and disuse, some of his followers as we have

seen denied it dogmatically altogether. This they did on two grounds, first that they could not picture any mechanism by which the change in an organ (such as increase of size) could be represented by a change in structure of the germ-cell, and secondly that the experimental evidence which was brought forward in support of the inheritability of the effects of use and disuse would not stand critical investigation. Indirect evidence in favour of it, such as evidence that evolution had actually proceeded along the line of the increasing or decreasing use of certain organs, could at that period always be explained away by assuming the constant occurrence of small variations in all directions.

Let us consider the first objection to begin with. It rests on the theory that the nucleus of the germ-cell is a kind of machine with parts working in a fixed relation to one another, and that somehow this machine by its action produces the organs of the adult animal in their typical arrangement. This is Weismann's view, and it is only the old eighteenth-century theory of "evolution" or "preformation" under another name. It has been utterly exploded by the progress of experimental embryology. Driesch and Hertwig have proved that the nuclei in a developing embryo can be shuffled about like a handful of marbles, and that this rearrangement produces no effect on the course of development. The mechanical picture of the germ-cell breaks down on investigation; we can form no simple picture of how the tendencies to produce the normal organs are represented in the germ, and hence we need not feel perturbed by our inability to imagine how the change in an organ produced by use is represented in the germ-cell.

The second objection, viz. the absence of good experimental evidence, we can give a much more decided answer. Within the last fifteen years carefully devised experiments have proved beyond reasonable doubt that the effects of use and disuse are inheritable. The most satisfactory of these have been carried out by Kammerer in Austria and Durkhen in Germany: and a very brief account of some of these may now be given.

Kammerer's Experiments on the Inheritability of the Effects of Habit

Kammerer reared the common Fire Salamander, which lives in Central Europe, and can usually be purchased from animal dealers in this country. The skin of this animal is of a black colour diversified by large patches of yellow. The eggs begin to develop inside the womb of the mother, who produces eventually about twenty young at a birth. These young have all four limbs developed, but they are provided with three feathery external gills on each side of the neck and live in water for six months. Then they come on land and the gills drop off and they grow up gradually, only attaining their full size and becoming sexually ripe at the age of four and a half years. They live on grubs and worms and frequent the woods and valleys. There is an allied species called the Black Salamander whose skin, as the name indicates, is entirely black. This animal lives on the cool upland Alpine pastures and produces only two at a birth, which are devoid of gills and ready at once to take up the life of their parents. Now Kammerer showed that when the Black Salamander was gradually accustomed to living under warmer and moister conditions, it began year by year to produce more young at a birth, and that these young were born at an earlier period of development, so that at birth they showed the stumps of gills. When these young were reared under the same conditions as those to which their parents had been exposed, they exhibited the tendency to produce more offspring at a birth in stronger degree than did their parents, and finally in this generation

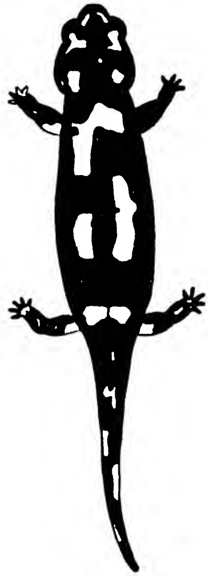

Fig. 10. — The Fire Salamander (*Salamandra maculosa*) seen from above.

Kammerer obtained animals which produced a dozen gilled young at a birth, and these young took to the water and lived in it just like the young of the Fire Salamander. Kammerer then undertook the reverse experiment; by rearing the Fire Salamander under cooler and drier conditions he induced it to produce fewer young at a birth; and these few were born at a more advanced stage of development, and finally he obtained Fire Salamanders which only produced three young at a time and these young had only the vestiges of gills and at once began their life on land.

Kammerer succeeded also in modifying the colour of the Fire Salamander. He took the animals directly after they had lost their gills and reared them in square boxes (open to the light of the sun above). Only one animal was kept in each box. Some of the boxes were painted bright yellow inside and others were painted black. The young animals varied a good deal in the development of the yellow pigment, and specially black specimens were chosen for the yellow boxes and specimens with a great deal of yellow in their skins for the black boxes. As the animals grew to maturity in the yellow boxes the yellow spots on their skins increased in size and number, till they formed two rows of large bright yellow spots. When two such animals were mated together and allowed to produce offspring, these when they left the water already showed two lines of yellow spots on the back. When they were reared to maturity in yellow boxes the yellow spots enlarged and eventually fused so as to form two broad yellow bands, and the black pigment on the back was reduced to a narrow median line. If we now turn to the specimens reared in black boxes, Kammerer found that the yellow spots slowly diminished in size: their borders became sprinkled over with minute black dots, and finally when the animal had reached maturity only a few small yellow spots were left. When such animals produced offspring and these offspring were reared in black boxes the yellow pigment was completely eliminated, and the salamanders became indistinguishable in appearance from the Black Salamander (*Salamandra atra*).

Most interesting results were obtained when the parents were reared under one set of conditions and the children under other conditions. Thus when the offspring of salamanders which had grown up in yellow boxes were reared in black boxes, the *yellow spots increased in size for the first six months of the animals' life*, thus showing that the effect of the experience which the parents had undergone still worked on the offspring even though the environment had been changed. At the end of six months, however, the effects of the black surroundings began to make themselves felt, the borders of the yellow spots became invaded by black pigment, and from that time on until maturity was reached the spots continued to diminish in size.

We may sum up Kammerer's results thus. The animal responds to a change in environment by an alteration in the proportions of its pigment: this response produces an effect on the offspring so that they tend to start where their parents left off; if they continue to live under the same conditions as did their parents, the effect of the environment is intensified; if they are exposed to different conditions, then the effect of the experience of the parents still shows itself during the early period of their life: *in a word the young recapitulate the response which the parents had learned to make.*

Durkhen's Experiments on the Effects of Habit

The results of Kammerer have been entirely confirmed by the completely independent work of Durkhen. This researcher chose as his subject the caterpillars and pupæ of the common white butterfly (the so-called Cabbage-White), *Pieris brassicæ.* The pupæ are usually of a greyish white colour which varies from an almost pure white to a dirty grey. Some few of the pupæ are, however, of a bright green colour: this is due to the entire absence of colour in the skin, which is transparent and allows the green blood of the animal to shine through. Under normal conditions only four per cent of the pupæ show this green colour. When, however, the caterpillars are reared and allowed to pupate in boxes with lids made of orange glass so that only orange light penetrates, then the formation

of white and grey pigments is largely inhibited and sixty-six per cent of the pupæ are green. When these pupæ were allowed to produce butterflies and these butterflies laid eggs, the resulting caterpillars were divided into two lots; one lot were reared like their parents in boxes with orange-glass lids, whilst the other lot were reared in the open. Of the pupæ produced by the first lot, no less than ninety-five per cent were green, whilst those of the second lot still had thirty-four per cent of green pupæ as contrasted with the four per cent normally produced. So we see that, as in the case of the salamander, when parents and children are exposed to the same environment the results are intensified in the case of the children; and when the children are placed in a different environment the results of the parental environment still make themselves felt.

We consider that these results of Kammerer and Durkhen are literally epoch-making for the theory of evolution in zoology: they show us evolution in action; and the mainspring of evolution, as Lamarck said over one hundred years ago, is the response of the animal to its environment, in plain language acquired habit. Just as in the formation of habit the action becomes easier with every repetition, so as the generations succeed each other the response to the same environment becomes more readily called forth, till at last, as for instance in the formation of eyes in embryos carried in the darkness of the mother's womb, the structures originally called forth by the habit are laid down before the exercise of the habits is begun.

If we now ask not how a species has become modified, but how it has become split into two species, the answer is at once that some of the descendants have adopted one set of habits and another set another kind of habit; in a word that what Dr. Tate Regan, Keeper of Zoology in the British Museum, calls *habitudinal changes* are the cause of the evolution of different types from common ancestors. Dr. Regan has shown for instance that the great majority of fishes inhabiting the great lakes of Central Africa are so closely related in their general appearance and structure that they must be regarded

as descendants of a single species which originally colonized the lake, but that these fishes are now divided into a number of distinct species differing from one another in the structure of the jaws and teeth according to the different habits which they have adopted.

But what, it may be asked, drives animals to adopt different habits from those to which they have been accustomed? The answer is, *necessity* and *opportunity*. The Mappin Terraces in the Zoological Gardens of London are surmounted by miniature crags of concrete, on which different species of wild goats live. Before the war each species kept to its own peak and its members only mated with their like. But during the war, when their numbers were reduced by death and it was impossible to replenish them with importations from outside, the members of different species began to mate with one another and this habit has persisted ever since. Every species in nature has to pass through occasional periods of scarcity when its natural food runs short; it will then seek to replace its normal nourishment by another kind if another kind is available, and if this attempt is successful, the new habit will tend to persist and eventually to cause modified structure.

M'Dougall, our best authority on Comparative Psychology, put the matter thus: " The activity of an animal is aroused by a stimulus, is directed towards an end, and does not cease until either that end has been attained or the animal is exhausted. *If the end cannot be attained by one means the animal will attempt to gain it by another.*"

Thus we see that evolution is inextricably bound up with the fundamental character of life itself, for the great distinction which divides the living from the dead is just this capacity for response. We have, it will be observed, been driven to regard habit as the really controlling mechanism in evolution because of the evidence that minute differences between members of the same family reared under the same conditions are not inheritable, and because of the pathological character and rarity of mutations. But there are certain well-known difficulties in the way of accepting habit as the sole cause of the

change in species, and these must now be fairly faced. They are mainly two, viz. (1) the occurrence of neuter insects, and (2) the phenomena of mimicry.

Neuter Insects

Every schoolboy knows that in the hives of bees and in the mounds of the so-called white ants there are what are known as " worker insects ". These never develop ripe genital organs and therefore never have offspring, but they have distinctive characters. It is therefore quite obvious that the results of their striving cannot be passed on to the next generation, and can have played no part in the development of their own structure. In the case of the white ants the problem is further complicated by the appearance of two kinds of neuters, one sort distinguished by larger heads and jaws being termed soldiers.

There is, however, a considerable amount of evidence to prove that these differences are primarily due to differences in the nutrition of the young insects, and that the peculiarities of the neuters must be regarded as arrested growths and pathological deformations of the organs of the normal fully developed insects (the so-called kings and queens). If we take the bees first we find that all the workers are imperfectly developed females, and that when a female is to be reared to full sexual maturity the egg is deposited in a larger cell, more richly supplied with honey than is the cell in which the egg destined to produce a worker is deposited. In the case of the common white ant of Sicily (Calotermes), Grassi asserts that the workers—if the queen should die—will produce a new queen by specially feeding up one of the grubs; and he further asserts that if more soldiers are wanted these can also be produced by special feeding.

It is true that some American workers have striven to controvert these results, and assert that the various types of insect can already be discriminated when the grubs are first hatched. But the type which these researchers say that they are able to distinguish at this early period of development is the future

perfect insect which afterwards develops wings and complete genital organs. They are not able to discriminate the grubs which are going to develop into workers and soldiers respectively until a much later period in life; and this is the critical point at issue: for it is contrary to what is known of bees and is *a priori* unlikely that an egg should be fated from the beginning to undergo a complete development irrespective of its environment. Another fact which renders it probable that the production of soldiers is due to some kind of abnormal nutrition is that in primitive Termites, as Fryer has shown, they may be made out of males as well as females.

Mimicry

If we now consider the phenomena of mimicry, we must explain that by this term is meant a superficial resemblance in shape and colouring between one animal and another which belongs to a totally different family or even order from the first. It is assumed, often on very insufficient evidence, that the one of the two animals which is the commoner has some peculiar feature—such as a repulsive odour or taste, or a powerful weapon of defence such as a poison gland—which makes it dangerous to the animals which would attack it, and that these learn to recognize it and avoid it. The species which resembles the dangerous species is always rarer and is assumed to be comparatively defenceless and palatable to its enemies; and it is held that the predatory animals mistake the defenceless species for the dangerous one and that so the defenceless one escapes.

The best examples of mimicry are found amongst insects and especially amongst butterflies. To give one example, the family Danaidæ includes brightly coloured insects which are believed to have a disgusting taste and which are therefore not attacked by birds. A friend of mine once informed me that he had seen the common North American species *Danais archippus* fly slowly and nonchalantly through a crowd of sparrows, a thing that no other butterfly would do. The family Papilionidæ, which includes our rare Swallow-tails, are said

to be eagerly snapped up by birds, and the same is true of the family (Pieridæ) to which our common Cabbage-white belongs. Various members of these families present a striking resemblance to Danaidæ in the general pattern of colour on the wings. It is supposed that at some previous period these Papilionidæ and Pieridæ, which lived in the same territory as the Danaidæ, " happened " to resemble the latter sufficiently to gain respite from the fierce persecution from which they suffered, and so were enabled to survive in larger numbers. Then random variations occurred, and those that increased the resemblance gave to their possessors better chances of survival and so the " mimicry " was gradually perfected.

Now there are two questions involved in this theory which must be kept entirely separate from one another, viz. (1) Do the mimics really escape on account of their mimicry, and (2) How has the mimicry come about?

On the first question the evidence is certainly conflicting. It must be remembered that more exact research has shown that the insect which is " mimicked ", and which we may call the " model ", is sometimes as edible as the mimic, and in other cases the mimic is actually more numerous than the supposed model, so that an enemy seizing one of these insects would have a better chance of obtaining something appetizing than something distasteful. We shall assume, however, that in some cases at least the mimic escapes on account of its resemblance to the model, and we now come to the second, which is the really vital question. We have given to our readers strong reasons for disbelieving altogether in random variations, and therefore what we have to explain is why evolution has set in such a direction as to cause these insects to resemble one another.

Now Eimer has shown that the changes in coloration which the mimic is supposed to have undergone, in order to increase its resemblance to the model, are of a kind which supervene independently in all families of butterflies and moths as *a reaction to climatic conditions.* These changes take place in some families more quickly than in others, and what happens

in real " mimicry " is apparently that individuals which have reached a certain stage in this process are favoured by natural selection.

We do not claim that we have given a complete or fully satisfactory theory either of the origin of neuter insects or of mimicry, but we wish to impress on our readers that all these phenomena are as a drop in the bucket compared with the vast sea of facts which tell in favour of habit as being the prime cause of evolution.

But at this point the critical reader will at once raise the question: " How do we know what course evolution has pursued in any particular instance? and unless we have independent knowledge of this course, how can we be sure that habit has been the deciding factor in it?"

Now absolute knowledge of the course taken by evolution could only be obtained if we had the notes of some angelic recorder who had watched the process taking place. We rely on hypotheses of various degrees of probability, but the probability is so great in certain cases as to produce unanimity in the minds of all the experts who have given special attention to the subject. These cases constitute our starting-point from which we set out to explore the probabilities in more doubtful instances.

Indirect Proofs of the Inheritability of the Effects of Habit: The Evolution of the Camel

We rely on three classes of evidence, viz. (1) the comparison with one another of nearly allied species and genera: this is what is termed Systematic Zoology; (2) the life-history or development of particular species: this is termed Embryology; and (3) the comparison with one another of the fossils in successive strata of rock: this is what is called Palæontology. We shall consider the palæontological evidence first as it is in many respects the best.

When Darwin wrote *The Origin of Species* he lamented the fact that the evidence from fossils was so scanty and unsatisfactory and afforded so little support to his theory—a circum-

stance that was strongly emphasized by his opponents. He gave various good reasons for what he called the imperfection of the geological record, and pointed out that fossils could only be preserved under exceptional circumstances. Since his time matters have considerably improved. We have become acquainted, especially in North America, with vast areas where the deposit of sediment went on regularly year after year for millions of years, and in these sediments are preserved the remains of the animals which inhabited the neighbourhood. We may describe a little more fully one of the best instances of this. The area now occupied by Utah and the neighbouring states in North America is at the present time a high and somewhat arid plateau trenched by deep gorges through which the rivers run to the sea. The most famous of these gorges, the Grand Cañon of Colorado, is 5000 feet deep, and the edges of the strata of which the plateau is built up are exposed on the sides of this gorge like the leaves of a book.

In Eocene times (that is in the period which followed the deposition of our chalk) the surface of the plateau was nearly at sea-level, and it was traversed by sluggish rivers which meandered slowly to the sea and which every spring were subject to great floods which covered the lush meadows bordering them for many miles. In these floods many of the animals which grazed on these meadows were drowned, and when the floods receded their bones were left embedded in the layer of mud deposited from the flood. In this way every year a sample of the population inhabiting the plains was preserved. As time went on the plains were gradually elevated above the sea and the rivers began to cut deeper channels in the lower parts of their courses. The climate changed and the vegetation with it, and as the rainfall diminished the succulent plants of early times gave place to the harsh dry herbage of a later period. The deposition of silt continued right through the Eocene and the succeeding Oligocene and Miocene periods and up till the beginning of the Pliocene period, and the record only ceased with the approach of the great glacial period of the Northern Hemisphere.

Now in the lower strata there are preserved the remains of four-toed grazing animals somewhat intermediate in structure between a pig and a deer. These animals had a primitive type of back-tooth—which incidentally the human race retains—viz. one studded over with tubercles and adapted only for crushing comparatively soft food, and there was a complete set of teeth in both upper and lower jaws. As we proceed upwards in the series of deposits these animals gradually change into camels. The outer toes diminish in size and finally disappear, and the upper bones (i.e. the bones of the palm and sole) of the two inner toes cohere together—as they do in cows and deer—and finally the lower ends of these toes diverge so as to give the characteristic splay-foot of the camel which fits it to walk on yielding sand. The whole change is the record of a reaction to the passage of the swampy meadow of early times first into firm ground and lastly into sandy steppe. Whilst the feet were changing thus the teeth were also being modified. The tubercles covering the back-teeth of the early forms became united into curved hard ridges, the front teeth of the upper jaw dropped out one by one, and the whole masticating apparatus was adapted to grind the hard woody desert plants which form the normal food of the camel and of its South American allies, the llama, alpaca, vicugna, and guanaco. Nevertheless so closely similar are the successive steps in the series that we cannot say at any one point "Here the camel began".

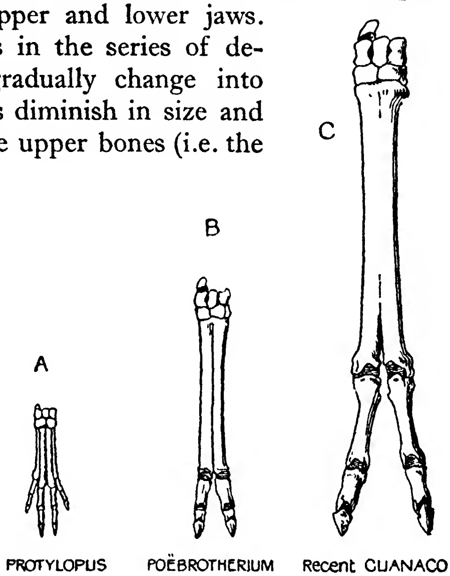

Fig. 11.—The fore-feet of the Modern Guanaco, a South American Camel, and of two of its North American ancestors, Poebrotherium and Protylopus.

In the same strata are preserved the records of the evolution of the horse. They, like the camels, began as four-toed animals with back-teeth covered with tubercles. As evolution proceeded they became three-toed by the loss of the little toe, and then the outer toes became gradually shorter and more slender and finally disappeared from view, leaving the one-toed horses and donkeys of to-day. It must be remembered, however, that even in these animals traces of the missing toes persist as "splint bones" hidden under the skin of the fore and hind legs. In following the series of strata the rate of decrease in size of the side toes is so slow and continuous that, as one palæontologist has expressed it, "they diminish by millimetres at a time". The teeth, meanwhile, like those of camels, were changed into efficient grinding organs by the union of the tubercles into ridges, but these ridges run obliquely across the teeth and not along them as they do in camels, and in horses the upper front teeth do not fall out. The most interesting point about the development of the horse is *that it was not one species which underwent this modification but several*, and as there are minute and apparently insignificant details which distinguish the teeth of horses and donkeys to-day, we are enabled to recognize their ancestors by the same marks and to assert that in Miocene times there were three-toed horses and three-toed donkeys which independently developed into the horses and donkeys of to-day.

Indirect Proofs of the Inheritability of the Effects of Habit: The Evidence of Systematic Zoology

Coming now to the evidence afforded by systematic zoology as to the course of evolution, we see at once that inferences from it involve a rather dangerous assumption. This assumption is that some species stood still and retained the ancestral form and habits whilst allied species became modified. Nevertheless there are many cases in which this assumption appears to be sound. Squirrels, whose form and habits are familiar to all, are very much alike wherever they occur all over the world; the Canadian squirrel is especially familiar to Londoners as

it has been introduced into the Royal Parks and is rapidly multiplying. It can often be seen leaping from branch to branch in Kensington Gardens. But in Canada there exists another and rarer variety, the so-called flying squirrel, which has a parachute-like expansion of skin reaching from the knee to the elbow. This squirrel is capable of taking colossal leaps of seventy to eighty yards in length during which it " vol-planes " through the air supported by its parachute. Does anyone doubt that this species has been developed from the normal type by becoming continually adapted to making longer leaps? Thus systematic zoology can show what course evolution has followed in the case of an isolated species amongst the other species of a genus, when the majority have a uniform type of structure and habits, and the same reasoning applies to an isolated genus amongst the normal genera of a family.

The reasoning becomes much more doubtful when we ascend higher in the scale, because it becomes more difficult to be sure that one family or one order has remained unmodified and can be taken as representing ancestral structures whilst others have changed.

The case of the flying squirrel, however, raises another question which is of far-reaching significance. This squirrel lives to-day in the very same woods as those inhabited by the common squirrel: yet the latter appears to thrive quite as successfully as the flying squirrel. The peculiarities of the flying squirrel must therefore have arisen in a different region, where trees were sparse and where it was exceedingly dangerous to descend to the ground, but having evolved its peculiar habits there it has spread into more normal situations.

The third source of evidence for the past history of animals is their life-history, and it is in many ways the most important of all the three. The significance of the life-history was first clearly enunciated by Haeckel in 1866, when he stated what has been called the fundamental law of biogenetics, viz.: " Ontogenesis or the development of the individual is a short and quick repetition (recapitulation) of the past history (phylogenesis) of the tribe to which it belongs ". Expressed in more

familiar terms this becomes the aphorism that " Every animal in its development from the egg to the adult climbs its own ancestral tree ".

Now this law was inferred from the resemblance between the young of the higher forms and the adults of allied forms lower in the scale of life; but it has been proved by direct experiment only in recent years by Kammerer. This experiment has already been described—it is that in which Kammerer, after having reared his salamanders in yellow boxes and thereby induced them to increase their yellow pigment, allowed them to produce offspring and then reared the offspring in black boxes. These young salamanders during the first six months of their lives increased the quantity of yellow pigment in spite of their black surroundings, and this can only be due to the inherited effect of the parental habit.

Indirect Proofs of the Inheritability of the Effects of Habit: The Life-history of the Cat-fish

A very clear case that the life-history is really the ancestral record of the species has just been worked out in the zoological laboratory of the Imperial College of Science in London. The so-called Cat-fish are fresh-water fish found in rivers and lakes all over the world but not in England. They derive their name from the feelers or " barbels " which protrude from the upper and lower lips at the corners of the mouth, and which have been fancifully compared to the whiskers of cats. These feelers are used for stirring up the mud at the bottom of the streams and dislodging the worms on which the fish feed. Now there are in India several genera of these Cat-fish which have learned to come to the top and breath air; they are thus enabled to live in water which is too foul for ordinary fish. In one of these genera which is called Clarias, there is an organ for absorbing the oxygen from the air situated under the gill cover above the gill arches. This organ has the form of two outgrowths from the skin of the side of the head. They spring from the upper ends of two gill arches and when fully developed they resemble bunches of grapes. In the young

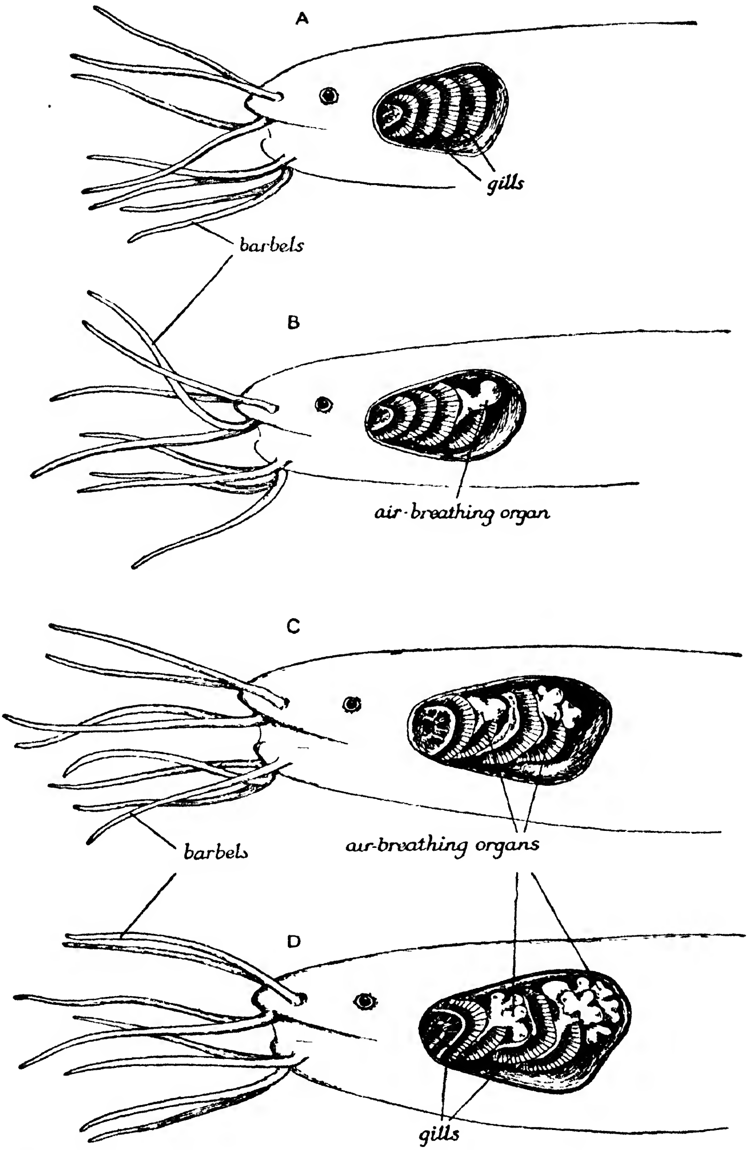

Fig. 12.—Four Stages in the Development of Clarias, the Poison Cat-fish of India

The operculum or gill cover has been cut away in order to reveal the gills and air-breathing organs.

Clarias these organs are completely absent and it is just like other Cat-fish, but as it grows they begin to sprout out and gradually attain the adult condition. Does anyone doubt that this Cat-fish in its growth is repeating the past history of its tribe? But all students of embryology from Haeckel onwards have been actually aware that the effort to repeat ancestral history is not the only factor which enters into the construction of the development of animals. To discuss all the disturbing factors would involve writing a treatise on embryology and would far exceed the limits assigned to this article; we shall therefore mention only one of them, viz. the effort of the mother to safeguard her offspring by carrying them for a certain period in her womb and feeding them with her own secretions. Under these circumstances the free-swimming young or "larva" of the lower forms becomes the "embryo" of the higher types. A good example is afforded by the human embryo. This embryo is on its ventral aspect distorted out of all recognition by its adaptations for drawing nourishment from the mother's blood, but on its dorsal aspect and in its head region it still presents a ludicrous resemblance to the tadpole of the frog.

When, however, a large number of life-histories are compared with one another it is possible to detect and allow for the secondary disturbances and to unmask the primitive ancestral element in them, exactly as the historian by comparing together primitive documents can arrive at a good idea of the truth by stressing those points in which the documents agree and discounting those in which they differ.

Once it is realized that this discovery of ancestral history (naturally only in its broad outlines) can be successfully accomplished, we see at once why embryology is of such vast importance in tracing the course of evolution. For the study of systematic zoology can only give us with any certainty the most recent changes accomplished by evolution, and the study of fossils can only instruct us as to the history of these animals which had hard parts, and moreover this knowledge of hard parts only avails where these parts are intimately

related to the soft parts lying around them and allow the structure of these soft parts to be inferred. Thus the most satisfactory fossils are those of the Vertebrata, to which we and the higher animals belong, and those of the Arthropoda (a group which includes crabs, lobsters, shrimps, spiders, scorpions, and insects). We have abundant remains of the shells of Mollusca, but as to what the animals were like which inhabited them we know very little.

But from the data derived from the embryology we can trace the evolution of all the principal groups of the animal kingdom from one-celled ancestors or Protozoa, and we are thus enabled to get a glimpse into the dawn of life at a time many millions of years before the first fossiliferous beds were laid down.

Evolution of Annelida and Mollusca deduced from Embryology

We propose in conclusion to describe briefly one of the great discoveries of embryology, which has enabled us to prove that two widely different groups of animals have sprung from the same ancestors, and at the same time to obtain an insight into the reasons why this cleavage of one stock into two such divergent groups has taken place.

To one who considered only their adult structure and present habits no two classes of animals could appear more sharply contrasted than the segmented worms and the molluscs.

The former are familiar to most of us in the shape of their commonest representative the earthworm, which is, however, a poor specimen of its class. A better idea of these animals is obtained if we examine the lug-worm which is dug up out of our mud-flats by fishermen for bait, but the best example of such worms is the so-called White Lug which also is used for bait on certain parts of the coast. This worm, the scientific name of which is Nereis, is provided with a head armed with feelers or tentacles followed by a long body divided into similar segments. Each segment is produced at the sides into wing-like outgrowths (parapodia) armed with bristles (chætæ), and

each segment likewise contains a ring-shaped section of the body-cavity surrounding the intestine which runs straight through all the segments towards the hinder end. There are two phases in the life of Nereis, as in that of most worms; during one phase it burrows in the sand or mud beneath the sea, and during the other it swims swiftly through the water using its parapodia as oars. It is during this phase that the male meets with and fertilizes the female, and this phase is represented in the life of the earthworm by its nightly ramblings over the surface of damp fields. The proverbial " early bird " surprises the latest of these nocturnal wanderers which have failed to return to their burrows by dawn. Many worms like the earthworm obtain their nourishment by swallowing earth or mud impregnated with organic debris, but Nereis is a predatory animal. The inside of its gullet is provided with sharp horny hooks, and it can turn this gullet inside out with lightning rapidity and seize with the hooks its unfortunate prey, which it drags into its burrow.

The Mollusca are represented by three principal groups: viz. (1) the bivalves, which include the clams, mussels, cockles, oysters, and scallops; (2) the snails, including under that term not only the well-known land snails but also the water snails and sea snails, i.e. the periwinkles, top-shells, cowries, whelks, and myriads of other forms; and (3) the cuttle-fish. These last, although they include by far the most highly organized of the Mollusca, we may leave out of account, since the average man only sees them in our few aquariums and in museums. All, however, are well acquainted with the first two groups.

If we confine our attention to these groups we find that Mollusca secrete a hard outer skeleton or shell as an exudation of a part of the skin, which is called the mantle, and that they can withdraw the rest of their bodies within the shelter of the shell. In the bivalves the shell is apparently divided into two equal pieces, right and left, but these pieces are united by a horny hinge which is really part of the skeleton; in the snails the shell is undivided and conical, but as it grows one side grows faster than the other and so it becomes spirally

twisted. Both bivalves and snails move forward without wriggling, but the bivalves plough their way through the sand or mud by means of a muscular wedge-shaped projection called the foot, which sticks out behind and below the mouth; the snails on the other hand have a flat foot with which they can glide over a hard surface, as anyone can see who observes a snail moving up a wall. Neither clams nor snails show any signs of segmentation in their bodies, and in both the body cavity is undivided and represented by a small sac situated near the hinder end of the intestine.

If we now consider those bivalves and those worms which have the most primitive form of development, that is those species in which the mother does practically nothing for the welfare of her offspring, we find that the fertilized eggs are simply shed into the sea and left to take their chance. In both groups these eggs develop into a little free-swimming organism called the *trochophore*, which is identical in structure in primitive worms and in primitive molluscs. American zoologists who have examined their structure with care have found that the trochophore of the worm corresponds to that of the mollusc, cell for cell. It is clear therefore that if development is a recapitulation of ancestral history the trochophore must represent in simplified form a far-off common ancestor for both groups. The question then arises: what was this ancestor like? The trochophore is shaped like a somewhat flattened sphere. At the north pole there is a thickening of the skin called the apical plate bearing a tuft of long stiff hairs which appears to be a delicate sense organ. Round the equator there is another ridge of thickened skin carrying long powerful vibratile hairs or cilia. This is called the prototroch: it is the organ by which the trochophore swims and by which it wafts food into the mouth. The mouth is behind the prototroch; it leads through a short gullet into a globular stomach from which an intestine runs back and terminates near the south pole in the anus. At the sides of the intestine are two small dense patches of cells called mesoderm, which later become hollowed out and form the rudiments of the body-cavity. In front of the anus there

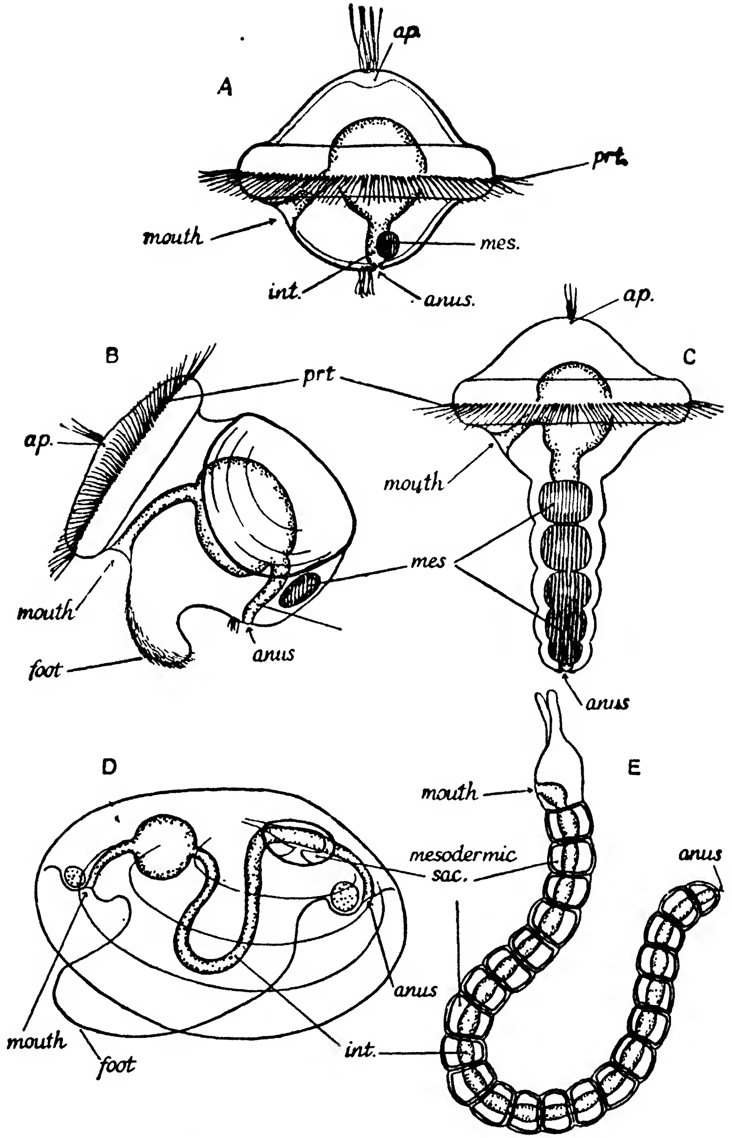

Fig. 13.—Diagrams showing the Structure of the Trochophore and its passage into the Annelid and Mollusc respectively

A, the trochophore. B, a molluscan larva. C, a worm-larva. D, a young bivalve mollusc E, a young worm. *ap.*, apical plate. *int.*, intestine. *mes.*, mesoderm. *prt.*, prototroch.

is usually a terminal tuft of cilia called the telotroch, and usually but not always a belt of cilia runs from the telotroch to the mouth.

Now if we examine the early stages of the development of the trochophore in both worms and molluscs, we find that the prototroch begins as four separate lozenges of cells carrying cilia, and that these only subsequently unite together. Also both mouth and anus are represented only by a single opening (the blastopore) which divides later into mouth and anus. There exists still a group of delicate transparent animals which throughout the whole of their lives swim at the surface of the sea. These beautiful creatures are called Comb-bearers (Ctenophora); they are in their primitive forms spherical with a thickened plate carrying sense hairs at one pole, and they have meridional bands of thickened skin carrying strong cilia by means of which they swim. There is only one opening to the gut situated at the lower pole. The trochophore may well represent an ancestor which if it lived now would be described as a simplified ctenophore.

We can now examine the changes which the trochophore undergoes in becoming a worm or a mollusc respectively. In the first case the part of the body behind the prototroch grows longer. This involves the lengthening of the intestine and of the rudiments of the body-cavity. The latter become divided into segments, and these segments become hollowed out so as to form the sections of the body-cavity. At the same time delicate grooves appear marking out the body into segments, each of which contains one of these sections of the body-cavity. Finally the prototroch is shed, and the animal drops to the bottom and takes on the wriggling, burrowing habits of the worm. When the trochophore becomes a mollusc, on the other hand, the hinder part of the body likewise grows, but it increases in height rather than in length: in fact the back becomes humped. It is this hump that is first covered by the shell, which in both bivalves and snails is at first a simple horny cup. To the lower edge of this cup on either side become attached the two valves of the bivalve shell, whilst in the snail

the thicker shell becomes added in an unbroken layer all round the edge of the cup. Nevertheless in the oldest snail shells known to us, and in one or two forms still living at the present day, the hinder edge of this cup is marked by a deep slit, which shows that the bivalve form of shell was the original one.

The foot grows out as a projection of the ciliated band connecting mouth and anus and is itself covered with cilia. Finally, as in the growing worm, the prototroch is shed; the animal drops to the bottom and begins to glide over it by the cilia on its foot.

The whole course of events has now become clear. The original ctenophore began to seek its food on the ground and to creep over it. Under these circumstances two courses were open to it. It might either keep to the surface and develop a foot as a means of gliding over the ground, or it might elect to move by active wriggling movements and seek safety by burrowing into the ground. These latter habits led to the division of the body into segments and to the division of the body-cavity into sections. If, however, it kept to the surface it became a mollusc, and the distinction between bivalve and snail arose from the kind of ground over which it travelled. If this was soft the mollusc began to plough into it, and consequently it could keep on an even keel and the shell developed as equal right and left valves; but if the ground was hard and uneven then inevitably the big hump on the back of the mollusc fell over to one side. This led to increased growth on one side and diminished growth on the other, and so the spiral shell of the snail came into being.

Had we space to pursue the subject we could show from a study of embryology that every great cleavage in the animal kingdom began in just the same way as the division between worms and molluscs. It can be shown that creatures so diverse as the Echinodermata (including starfish, sea-urchins, &c.) and the Vertebrata also arose from the simple free-swimming ancestors, and that the various groups of Echinodermata (starfish, brittle-stars, sea-urchins, and sea-cucumbers)

owe their divergences of structure entirely to the fact that different groups of primitive Echinoderms adopted different habits. We could show that out of primitive worms the ancestors of shrimps and insects were developed by the thickening of the skin and the transformation of the parapodia into limbs; in fact wherever we look in the animal kingdom we find that *habit is response to environment and that inherited structure is nothing but the crystallization of the habits of past generations.*

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CHAPTER VII

Physiology

Physiology is a branch of biology, and as such has not only supplied important evidence for Evolution, but has been profoundly influenced by the Darwinian theory. The effects can be traced clearly, but it is a matter for surprise that they are not more obvious and definite. The reason is to be found in the fact that in recent times physiology has been studied and even defined as the physics and chemistry of life. The great influence of this conception of the province of physiology is shown by the development of the subdivisions known as biochemistry, biophysics, and psychophysics.

Although this trend is not biological, there is little doubt that the stimulus was given by the theory of evolution; the revolt against the old belief, that each species arose from a special creation and each organ was designed for its special purpose, stimulated investigation along physical and chemical lines. The goal was now the demonstration of the origin of life by a natural process acting on non-living material—spontaneous generation. The background of theological belief or disbelief gave a further zest to the search for physical and chemical explanations of physiological processes.

Other theories produced an effect, but did not deflect the materialistic school of physiology from its path. The cellular theory influenced physiology profoundly, especially in this country in which histology developed in the closest association with physiology; the cell was the unit, and attempts were made to study the relation between the structure and functions of

the units by investigations upon isolated tissues and surviving organs.

There was a time, well within the memory of the older physiologists of the present day, when lively hopes were entertained that the study of muscle and nerve from the points of view of chemistry and physics would solve the enigma of life, or at least afford a solution in physical and chemical terms. There are some who still cherish these hopes, but it is clear that a reaction has occurred.

The foundations of this belief, based on the so-called exact sciences, chemistry and physics, have been shaken. It is recognized that the isolated muscle and nerve and the surviving organs are not units of life; they are not living but dying portions of the unit. Even cultures of tissues are not in a physiological condition, not even in a pathological condition, but in a purely artificial one produced by the experimenter.

The Need of Biological Conceptions in Physiology

The physiological unit is the living organism, whether it be a single cell, such as an amœba, or a complex of millions of cells, such as a man. Physiology deals with living processes which cannot be described in anatomical terms, or even in terms of chemistry and physics; it is a branch of biology, and must be described in biological language. The most important influence in the return to biological conceptions in physiology has been in this country the work and teaching of Haldane.

In the first place will be considered the physiological evidence for the belief that man and all animals and plants are descended from one prototype.

It is reasonable to hold that there are latent in the lower or simple type, the protozoon, the capacities for a development of the physiological systems found in the highest or complex type. Life proceeds from life, the single cell possesses all the functions which cells ever did and will possess, functions in essence the same although obscured by hypertrophy in one or atrophy in another. There appears to be no

example of a physiological function which is found in one living type alone. Even in disease no new process arises; all pathological conditions have their representations in physiology.

Differentiation of Structure and Division of Labour. Physiology of the Human Embryo and Fœtus

If, as Darwin maintained, the descent of man is shown by the different stages of his development from the union of the ovum and the spermatozoon, agreement between the anatomical and physiological evidence should be found. There is agreement. In the embryo the physiological processes resemble those of the lower animals, and, as the latent capacities are unfolded, there is differentiation of structure accompanied by division of labour.

Although the difference between the ovum and the newly born child seems to be as great as that separating a protozoon from a mammal, the transition is so gradual that it is impossible to state when one stage ends and the other begins.

Darwin held that " as natural selection acts solely by accumulating slight successive favourable variations, it can produce no great or sudden modifications; it can act only by short and slow steps ". What is true for structure is equally true for function. The muscular fibre, the glandular cell, and the nerve cell of the infant have a common origin in the fertilized ovum; the cells of the primitive nervous system develop especially the property of excitability, the muscular fibres that of contractility, and the glandular cells that of secretion; in all cases the accentuation of one capacity is accompanied by the depression, but never the extinction of the others, all of which are present in the mother cell.

A continuity of function is as true as a continuity of structure. There is no beginning of nervous activity, muscular contraction, or secretion in the embryo, fœtus, or newly born child; within the ovum every physiological capacity is present in an active, subdued, or potential state.

At the birth of the child it might appear that there were

sudden modifications, a jump instead of short and slow steps. The difference is less than at first sight appears. There is evidence that the respiratory muscles are exercised and co-ordinated before birth, blood flows through the airless fœtal lungs, and between breathing by means of the placenta and the lungs there is no essential difference. At all stages, from the beginning to the end of life, the seat of the respiratory process is in the living cell, bound up, it well may be, with the activity of ferments.

Before birth the fœtus receives its nutrition from the mother's blood modified by the placenta; after its birth the child takes its mother's milk, derived from her blood after elaboration or selection by the mammary gland. The continuity of blood relationship is maintained in the food when the mother suckles her child. By a gradual weaning, which is the natural condition for both mother and child, the infant is afforded time to adapt itself to the digestion and absorption of foodstuffs of other origin. Adaptation is a slow process, both as regards structure and function. The neglect of this biological truth has produced a terrible mortality among the infants of the most civilized races.

The lower organisms are cold-blooded; their physiological processes are increased by warmth and diminished by cold. It is likewise with the embryo and fœtus of the warm-blooded animals, as will be shown by the evidence to be given later in connection with the development of the power of regulating the temperature of the body.

Evidence from the Nursery in favour of Evolution

The growth and physical training of the infant involve no physiological principles other than those observed in young animals, although the rearing of children has been made difficult by the conventions introduced by civilized races. The cry of a healthy infant is not due to pain or bad temper any more than the bellowing of a calf or the bleating of a lamb; it is a call to its mother for food or attention. The infant would suckle and take his food according to his needs, not, as the

modern nurse thinks he should, according to the clock or the convenience of his mother.

Throughout fœtal life there has been a progressive development of the power of muscular contraction and co-ordination, and at the time of birth this is seen especially in the capacity to grasp with the hands and feet. Infants on the first day of their separate existence can hang by their hands from a horizontal bar and support their own weight, it may be for as long as two minutes, a longer time than most adults would endure. The power of grasping with the foot is considerable; the great toe is abducted and the foot held more in the position of a hand. As the child grows up this power gradually fails owing to disuse, and is found developed in the adult only in cases of congenital absence of the arms and hands. Such prodigies may be seen at country fairs, exhibiting their skill in using their feet for all the purposes for which an ordinary man uses his hands.

These characteristics find an adequate explanation in the theory of evolution. It has been suggested that the infant of primitive man was carried in a manner similar to that seen in apes, the offspring clinging to the parent by grasping with its hands and feet the long hair in the axillæ and over the pubes. To grasp hair is well known to excite in young infants obvious expressions of delight and satisfaction. This explanation, moreover, would account for the great development of hair over the pubes and in the axillæ at the time of puberty.

As the infant grows he learns not only to control the muscles of his limbs, but also the relationship of the parts of his body to himself; this he does by trial and error, sometimes with comic results, as when he pulls his own hair so hard that the pain makes him cry, or sucks his thumb until it is raw. He is not taught to walk, notwithstanding the claims advanced by a fond mother. He crawls, pulls himself up by his hands, and gradually teaches himself to stand, walk, and run, for the capacity is in him as in the young of other animals, and in similar measure. Still later he begins to play in the instinctive manner seen in other young mammals. Thus from birth

onwards, or more strictly from the very beginning, there is progressive training, and all that is needed for the development of physical fitness is freedom in the open air during childhood.

It is unnecessary here to pursue further evidence from the nursery in favour of evolution. The important question of mental evolution and its relation to conditioned reflexes is one which can be considered more efficiently by the psychologist.

Variability as a Factor in Evolution

In the foregoing pages the physiology of the developing human embryo has been reviewed from the point of view of evolution. It is necessary now to examine the factors concerned in the process of ascent from a lower type—variability, struggle for existence, adaptation, survival of the fittest, and heredity.

Darwin maintained that " the more complex organs and instincts have been perfected by the accumulation of innumerable slight variations, each good for the individual possessor ". In physiology there has not been sufficient recognition of variability. As the result, it may be, of the neglect of the biological conception and the acceptance of physics and chemistry as guides, there has been and is still a widespread belief in so-called " normals " in physiological processes. As examples may be mentioned the pulse, the respiratory exchange, and the heat of the body. An extreme extension of this belief is found in the assessment of the physical fitness of men from certain measurements, such as height, weight, girth of chest, and vital capacity. Biological reasoning would have shown that such an assessment would be unreliable; the final appeal, experiment, has given a similar verdict.

There are in truth no normals, no constants. Physiological processes show ceaseless variations on either side of an apparent equilibrium. The physiological unit is the living animal, and the frequent expression of processes, such as respiratory exchange and metabolism, in terms of grammes per kilogramme of body weight is inexact and misleading; even when the

comparison is made in terms of square metres of the body surface the inexactness is mitigated only by the physiological conception in the background, the regulation of the temperature of the body.

The rate of the pulse of different healthy men may range from fifty to eighty per minute, and the frequency of breathing from ten to twenty per minute; similar examples could be drawn from other systems. Indeed one of the greatest difficulties in investigations is to determine the range of so-called "normality"; it is even open to argument whether there is any such condition, for what is a sign of health in one man may be a sign of disease in another. Even animals of the same litter may not be adequate controls, unless they happen to be identical twins.

Apart from the variability among different individuals, there is a personal variability of function, without which it would be impossible for the body to adapt itself to its varying needs and changes in its environment. One instance only need be given. During severe muscular work the demands for more oxygen and the removal of carbon dioxide are imperative. The heart and the lungs respond; the frequency of the pulse and breathing may be trebled, and other and more complex adjustments are made.

Numerous proofs of variability are afforded by everyday life. The performance of a definite piece of work by different men brings out at once the personal variation; there is no correct method, but a correct method for each worker. The style of skilled farm-labourers cutting grass or corn with a scythe is as personal and distinctive as the style of a sportsman, writer, or orator.

The progress of research has revealed the complexity of functions owing to a variability more extensive than that which was recognized formerly. The blood even of blood relations may belong to different groupings and be incompatible for transfusion. There is individuality in the secretory and motor activity of the alimentary canal; what is "one man's meat is another man's poison". There is a personal variation, it would

appear, in the chemical composition of all the tissues and in all the functions of the body.

The existence of these physiological variations, which are essential factors in evolution, is undoubted. The biologists have recognized variation; many physiologists have ignored it.

Use and Disuse as Factors in Evolution

Some consideration of the effects of use and disuse as factors in evolution is necessary. Examples are numerous. The frequent exercise of special groups of muscles in some forms of manual labour not only results in hypertrophy of those muscles, but also in a stronger growth of the bones from which they take origin and in which they are inserted. It has been mentioned already that the prehensile power of the foot in the newly born infant can be developed greatly by use, as it is perforce in cases of congenital absence of the arms. "Practice makes perfect."

Disuse produces atrophy, but not in the sense of complete loss of function; a muscle, if it be used but seldom, becomes smaller and weaker, but it is not replaced by fibrous tissue, and is capable of great development as long as its nervous supply remains intact. It would seem that use and disuse of parts can have little effect upon the fundamental physiological processes of the whole animal, notwithstanding the magnitude of the local effects. Weight and length are not physiological measurements; morphological characters do not alter physiological processes.

There appears to be no example of a function disappearing absolutely from disuse, disease, or mutilation; eyes may atrophy, but there are still photochemical reactions to be found in other organs; the auditory apparatus may be absent owing to congenital defect, but other nerves will respond to vibrations; the spleen may be removed without danger to life, but the other hæmolymph glands hypertrophy. Rudimentary organs, which were considered to be only useless relics of a bygone stage in the ancestry of the animal, have been found to possess important functions. The extinction of any one

physiological capacity involves the death of the organism. The gonads may be removed; the primitive capacity for asexual reproduction persists in the tissues; the individual lives, but the race dies.

Already, when a child is born, many of the cells which formed part of its body have lived and died after reproducing their kind and transmitting their characteristics; this birth and death of cells continues throughout life. In the case of the nervous system, however, the cells appear to persist, but cease to reproduce at an early age; hence a loss of nerve cells in the human brain is not compensated by regeneration. This limitation in the capacity of the nerve cell may be an advantage in the maintenance of the identity of the subject.

Are any Characters acquired?

The question of the transmission of acquired characters must be considered, for here the outlook of the physiologist may be somewhat different from that of the morphologist.

In the first place, what is an acquired character? The term appears to signify the special development or atrophy of some part of the body owing to changes in the environment or activity of the part. The muscles may become hypertrophied by special training; of this examples were common a few years ago during the cult of the so-called "strong man". Deformities, such as a small waist or a constricted growth of the feet in women, form another type, and at one time some biologists considered seriously the effects of removal or mutilation of unessential parts in the members of numerous generations, as in the case of circumcision in man and docking of tails in lambs. Another group of acquired characters is found in those due to disease. Does the presence of such characters acquired by the parents lead to the transmission of similar peculiarities to their offspring?

The physiologist might maintain that all of these examples, with the exception of those due to disease, were useless for the decision of the question; there would be no constitutional effect upon the parents, and it is difficult to imagine any reason

why the germinal cells should be influenced. Further it may be asked from the standpoint of physiology whether there are any acquired characters. No new physiological process is acquired; there is only the hypertrophy or atrophy of tissues or alterations in the co-ordination of organs as the result of use or disuse. Even in the case of disease all pathological processes have their representation in physiology; for example, hypertrophy of the uterus during pregnancy, hæmorrhage during menstruation and parturition, atrophy of the thymus gland, dry gangrene and separation of the umbilical cord, absorption of cells during the eruption of teeth, development of immunity to different foods or toxins, and inflammation as a physiological response to injury.

Evidence should be sought in the effects of the internal secretions, diet, and disease, which might influence the germ cells through changes in the composition of the blood supplied to them. The germ cells might suffer in nutrition owing to an excess or deficiency of internal secretions, ferments, and necessary constituents of diet.

The Germ Cells do not live a Life apart from the Common Life of the Organism

There is no evidence that the germ cells are shielded from the influence of the general conditions which affect the nutrition of the body. Indeed there is abundant evidence to the contrary, as the following examples will show. Ovulation is affected by the quality and quantity of food; wild rabbits breed at an earlier date if the spring is mild and food is plentiful; farmers appear to be able to quicken ovulation by " flushing " their ewes with food. Many wild animals will not breed if they are kept in captivity, and success in breeding from such animals appears to depend upon more natural conditions of life.

In man there is similar evidence. The activity of the reproductive glands in the case of both sexes is reduced by a scarcity of food. The onset of menstruation occurs late in cold countries, early in hot climates. In some primitive races there is evidence

of a definite breeding season in the spring. The alterations produced in metabolism by lactation are accompanied in many women by a suspension of menstruation for several months. Amenorrhœa is a symptom of many diseases.

The germ cells possess all the essential physiological capacities, and in their development from the mother cell have been supplied with the necessary materials from the organism of which they are a part. Differences in nutrition affect their ripening, their age at the time of fertilization, and exert, it is probable, a selective action upon the ova which reach maturity. There is an interaction between the germ cells and the other cells of the body; of this there is no doubt in the effects of diseases of the glands of internal secretion, diseases due to defective diet, and removal by operation or disease of the generative glands.

There appears from the physiological point of view to be no ground for the assumption that the germ cells are absolutely stable, and live a life apart from the common life of the organism. The variations made manifest in the offspring are latent in the germ cells from which they have arisen.

In mammals the difficulties of investigation are greater than in other animals, for the apparent effect of heredity may be due to the direct transmission of some influence to the fœtus during intrauterine life. It is known that in the placenta there may be an exchange of internal secretions between the mother and her offspring; for example, a defective secretion in the thyroid gland of either may be compensated by a supply absorbed from the blood of the other. In disease the virus, toxin, or antibody may be transmitted through the placenta to the fœtus.

On general physiological principles it would not be expected that grafts of germ cells would be changed in their individual characteristics by the influence of the stock in which they are embedded. In the first place such grafts are successful only in closely related animals; in the second place there is doubtless in the germ cells as in the other cells of the body the power of adaptation as well as the tendency to maintain their individual

characteristics; they in common with other cells possess the capacity of selective absorption and grow according to type. The growth of the germ cells may be antagonized by the influence of hormones derived from germ cells of the opposite sex, as shown by the differences in ovaries grafted in entire or castrated male animals, or by the interesting example of the " free martin ", an incomplete female, a twin with a bull calf, with which during fœtal life it had a common supply of blood. There are, moreover, numerous observations to show that the male and the female of even the highest animals contain characteristics of the opposite sex, and if these characteristics are latent they can be unmasked by senile changes, disease, or surgical operation.

The evidence from physiology would lead to the conclusion that in the strict sense there are no acquired characters, but only the greater or less development of structures and capacities present from the beginning. If this estimate be correct the question of the transmission of acquired characters does not arise. The germ cells are influenced by the other cells of the body and are liable to variation; they possess in a latent form all the physiological capacities of a cell and change only by the accentuation or suppression, but never the extinction, of those potential processes.

The advances made during the last few years in the culture of isolated tissues show in some measure how the growth of one tissue of a complex organism is influenced by others; there may be formed substances which promote or, on the other hand, inhibit growth. A glimpse is obtained of the ways and means of the correlation of tissues and organs and the influence exerted by changes in the internal environment. The results at the same time demonstrate clearly the limitations in the study of the physiological processes of an organism by experiments upon isolated parts of its body.

Physiological Processes of Animals and Plants

If the theory of evolution be true there should be no fundamental differences in the physiological processes of animals

and plants. This question is considered elsewhere, and it is unnecessary to examine here the similarity as regards reproduction, heredity, variability, and adaptation.

The respiratory processes in plants and animals appear, in the light of recent work upon oxidizing ferments, to be essentially the same. Even in the case of animals the capacity for anærobic respiration is well developed in intestinal worms, and there is evidence that the tissues of the higher animals retain some of this power.

At one time the formation of fat from carbohydrate was contested on chemical grounds, although the positive evidence from the physiology of animals and plants was concordant and adequate; even down to the present day the reverse process, the formation of carbohydrate from fat, has been doubted owing to difficulties of chemical explanation, but here again the agreement in the respiratory quotients in animals and plants affords definite evidence and strong support, not only for the reversible action of ferments, but also for the essential unity of living processes, whether they be found in the vegetable or animal kingdom. It is impossible, and ever must be, to decide on the evidence of pure chemistry what is and what is not possible in the laboratories of the living organism. Questions of physiology must be decided on biological evidence, and progress is delayed when the biologist awaits the uncertain guidance of the chemist and physicist.

The nitrogenous assimilation might appear to be a definite difficulty in the argument on the essential unity of animal and vegetable life. Is there a breach here? Fungi and insectivorous plants supply stepping-stones across the gap, but a continuous pathway should exist if there be truth in the view that no new physiological process arises in any form of life. A short time ago the common belief among physiologists was that animals absorbed nitrogen in the form of protein; this is no longer held, for the evidence available at the present time indicates absorption as amino-acids and deamination before combustion. In the case of bacteria it appears that, with the possible exception of the nitrogen-fixing and the nitrifying

organisms, the requirement is amino-nitrogen. There are, therefore, good prospects of a discovery of a continuous pathway.

The recent advances in the knowledge of the effects of sunlight and other rays upon animals have opened up a wide field of investigation, in which it is probable that another proof of the unity of physiological processes in animals and plants will be demonstrated—the utilization of solar energy in metabolism.

Evolution of the Warm-blooded Animal

Within recent years interesting evidence in support of the theory of evolution has been furnished by the results of observations upon the regulation of temperature in various classes of animals. A warm-blooded animal is distinguished by its capacity to maintain the internal temperature of its body at a level which is almost the same in the depth of winter and in the height of summer. This power of regulation is not possessed by the cold-blooded animals, and is not developed equally among the warm-blooded animals; its evolution can be traced in the animal series, and the individual bird or mammal during its passage from immaturity to maturity.

A rudimentary power of regulation is found in several groups of the cold-blooded animals. Insects as a class are cold-blooded, but many observations have shown that bees in a hive can maintain a temperature considerably above that of the external air. Vipers and pythons may have a temperature 10° above that of their surroundings.

The lowest mammals, the monotremes, possess only an imperfect power of maintaining the heat of their bodies at a constant level; the average temperature of Echidna and Ornithorhynchus is 29·8° C. (85·6° F.) when the air is 15° (59°), and shows a considerable variation when the temperature of the environment is changed. Echidna hibernates for a period of four months.

A further link between the two great groups, the cold-blooded and the warm-blooded animals, is found in those

higher mammals, such as the marmot, dormouse, hedgehog, and bat, which hibernate during the winter; they have acquired the power of regulating their temperature, but at the same time have retained some of the physiological characteristics of their cold-blooded ancestors. Their temperature is inconstant even during the summer, and in winter, when they are torpid, may be only 3° or 4° above the freezing-point.

The temperature of newly born puppies, kittens, rabbits, and rats falls when they are removed from the warm surroundings afforded by their dam, and continues to fall until it reaches a point a few degrees above the temperature of the air. Newly born guinea-pigs, on the other hand, are able to maintain their internal heat if the exposure to cold be not excessive; they are at birth in a condition of advanced development; they are well covered with fur, their eyes are open, and they are able to run about.

The young offspring of warm-blooded animals can be placed in two classes: those which at birth are blind, helpless, in some cases naked, and unable to regulate their temperature; and those which are born in a condition of greater development and capable of maintaining the heat of their bodies at a fairly constant level. Young birds can be classified in a similar manner; the pigeon is an example of the former, the chick well represents the latter class. The members of the first class respond to changes of external temperature in a manner similar to that of the ordinary cold-blooded animal; their combustion, as measured by the output of carbon dioxide, varies with, and in the same direction as, the temperature of their surroundings. The representatives of the second class increase their combustion when they are exposed to cold; they resemble warm-blooded animals. The development of this power of regulating the heat of the body by appropriate variations in combustion can be traced in the embryo chick.

The infant at birth does not possess the power of maintaining a constant level of bodily heat, and its temperature will fall if it be exposed to moderate cold. The use of an incubator for the rearing of premature infants is a practical recognition

of their incapacity to maintain their temperature; as in the case of cold-blooded animals, their exchange of material and their growth will be stimulated by warmth, depressed by cold.

Adaptation and Struggle for Existence

These examples afford evidence also of adaptation in the struggle for existence. The tissues of the body require a high internal temperature for the due manifestation of their activities; the warm-blooded animals maintain the optimum condition by a constant struggle against cold and heat; the cold-blooded animals have not developed this capacity, and within certain limits the activity of their tissues depends upon the external temperature. These conditions are advantageous to the respective groups of animals in the struggle for existence; the warm-blooded animals are able to live a more ardent life, unbroken by long periods of inactivity or torpor, and within very wide limits independent of the temperature of their surroundings. In the regulation of the production and loss of heat there is constant exercise of the different organs of the body, especially the nervous and the muscular systems; this in turn must lead to greater activity and development of the nervous system, and also greater intelligence in the warm-blooded animal. On the other hand, the food supply of the cold-blooded animals depends upon the external temperature; a period of torpidity, therefore, in which the activities of tissues are reduced to the lowest ebb consistent with the retention of life, tides the cold-blooded animal and the hibernating mammal over the winter, when the food is scarce or absent, and prolongs their life beyond one brief summer.

The evolution of the warm-blooded animal has been traced, but the nature of the structural changes bound up with the transition from the cold-blooded stage is unknown. The search after gross morphological differences would appear to be a fruitless one, for the capacity to regulate temperature may be suspended and in turn restored under natural conditions of hibernation. Observations of physiological as well as pathological conditions indicate that the most important

factors are not special " heat centres ", but the co-ordination of the nervous control over the skeletal and vascular muscles in response to sensations of heat and cold. On the theory of evolution the development of special heat centres would not be expected; a critical review of the evidence brought forward in support of such centres shows that there is only a gradual adaptation of pre-existing processes. There is no hard and fast line between the cold-blooded and warm-blooded animals, or between the cold-blooded and warm-blooded stage in a developing mammal; so should it be, if the theory of evolution be true.

The Theory of Evolution as a Guide in Physiology. The Development of the Mammary Gland

In order to demonstrate further the value of the theory of evolution as a guide in physiology, it is necessary to give examples of the advances made when the biological conception has been applied.

Until recent years the secretion of milk remained a unique and mysterious process for which no adequate stimulus could be found, notwithstanding the fact that lactation had been a condition of daily concern and study for the medical man and the farmer. Biology has thrown a flood of light upon the subject.

The mammary gland has given a name to the highest vertebrates, the mammalia, but there is evidence that it has arisen by no sudden appearance, but by a gradual modification of the sebaceous gland and of the sweat gland also, it may be, according to some authorities. In the lowest mammals, the monotremes and the marsupials, lactation is primitive, but nevertheless shows all the essentials found in the most highly developed mammary gland. The duck-billed platypus is a mammal which lays eggs; its mammary glands have no nipples, and the offspring sucks the milk-laden hairs of the specialized area of skin in order to obtain milk. In the pouch of the marsupial there are numerous sebaceous and sweat glands which undergo great hypertrophy during pregnancy; further-

more, a similar change is seen when ovulation is not succeeded by pregnancy. These facts would indicate that the stimulus to lactation is not to be sought in pregnancy, at least in these mammals, and if the theory of evolution be true, in any mammals, even the highest. Confirmation of the view that the stimulus arises in the ovary from the corpus luteum produced after ovulation is found in many facts, long known but unexplained.

The mammary gland develops at puberty with the onset of ovarian activity and shows phases of subdued action at each menstrual period. The menopause is accompanied by atrophy of the glandular tissue of the ovaries and breasts. Virgins, animal and human, have produced milk in quantity sufficient for the nourishment of sucklings. In infants, male as well as female, the appearance of so-called "witches' milk" is well known to every midwife, and may be explained by the absorption during intrauterine life of some of the internal secretion of the corpus luteum of the mother. There are numerous records of adult males, both animals and men, in whom the rudimentary mammæ have secreted milk in considerable quantities; suction has been an obvious factor, but it is probable that in addition there was a stimulus supplied by an internal secretion from gonads of a mixed type.

The activity of the sebaceous glands around the nipples and the sweat glands of the axillæ is increased during pregnancy, and the secretion of milk by accessory mammæ is common. It is well known that the generative organs have an influence upon the activity of the sebaceous glands of both sexes, for example, in the disfiguring disease called acne.

It is stated, moreover, that caseinogen, the characteristic protein of milk, is found in only one other organ of the body besides the mammary gland, namely in the sebaceous glands.

Such is the evidence, briefly stated, upon the development of lactation. The only connecting link in the various facts is to be found in the theory of evolution.

Physiology as a Guide in Everyday Life

It is admitted that the theory of evolution has exercised the most profound influence on modern thought, but the practical application of biological teaching to everyday life has been obstructed by the long established conventions of civilization. By a slow and tragic process of trial and error modern man is learning that a guide to life is afforded by physiology; in most cases this recognition of biological laws is not voluntary but forced by bitter experience. Man is obsessed by the idea of the theologians that the world was made for him, and that he can by civilization control the forces of nature and overcome biological laws and the animal nature within him.

If the theory of evolution be true this aim is bound to fail, for man's course is determined by his ancestry and environment, not by free will. Evolution is a slow, an infinitely slow, process, and as far as physiological processes are concerned the infant of to-day is in a similar position to that of an infant in prehistoric times. The difference is found in unessentials: a more artificial environment due to knowledge acquired and transmitted by tradition and writing. The child is born a primitive and very immature animal, and, as far as we can determine, has not acquired any new physiological capacities or lost any of those of its remote ancestors. The fundamental physiological needs remain the same, and the failures of civilization, and they are many, are due to the neglect of this truth. It may be of interest to examine these needs in more detail, for they should show the agreement between applied physiology and the theory of evolution.

In the struggle for existence it soon emerges that good and evil are relative; adaptation can be effected by higher development or by degeneration. An advance in the standard of living may bring about decay; hard times the regeneration of a race.

The fundamentals for a healthy and full life are food, muscular work in the open air, rest, shelter, a mate, and family;

the enjoyment of these entails a constant struggle for existence. Under modern conditions of civilization these needs are not adequately satisfied, and hence have arisen widespread unrest and discontent.

Food demands the first attention. On the theory of evolution it would be expected that the artificial feeding of infants would result in disaster; the lesson has not been learnt, and innumerable small graves throughout the country bear witness to the ignorance and criminal neglect of mothers in their first duty to their offspring and the race. The decline in infant mortality in recent years is due to the modern crusade of infant welfare, to the recognition of the primitive needs of a young mammal. The Great War afforded a striking piece of evidence. The scarcity of food, produced during 1916 and 1917 by the blockade, caused 800,000 deaths in Germany according to the Prussian estimates, but the death rate among infants was below the rate during peace; the mothers in greater numbers suckled their children.

The recent advance in knowledge of the accessory food-substances, the vitamines, affords evidence of a similar kind. In its long ancestry the adaptation of a child would be to natural foods, a certain amount of dirt, and the more prevalent bacteria. Nevertheless, the popular ideal, based upon the teaching of bacteriology, is sterilized food and stringent legislation to ensure clean milk, bread, and meat. The cost of food is increased, and the resistance of the child is diminished by the inadequate quantity and quality of the food.

The modern fear of germs is unreasonable and based upon inadequate knowledge; the crusade in favour of clean milk, if it be carried too far, will increase the cost of milk, and the boiling of milk deprives it of some of its most valuable properties. The healthy child resists the action of germs, and in the struggle for existence develops an immunity to the diseases common in its native land. In this country it is probable that the majority of children are exposed to the infection of tuberculosis and infected in some degree; resist-

ance is developed, and the risk of a serious attack at a later stage of life diminished. There is strong evidence in favour of the view that the development of resistance and immunity is far more important to the race than attempts to remove all risks of infection. It is well known that native races coming from countries free from tuberculosis fall an easy prey and die in large numbers when they are exposed to ordinary risks in parts of Europe in which tuberculosis is prevalent.

On the theory of evolution likes and dislikes are expressions of physiological needs, and this is supported by the old saying " one man's meat is another man's poison ". The child shows that he retains some of the primitive instincts which are a guide to life; he has a great liking for raw fruit, nuts, turnips, and swedes, which are regarded by his elders as indigestible. These raw foods have been recognized recently as rich in constituents especially valuable for healthy growth. The petty pilfering of orchards by children should be regarded as a sign, not of original sin, but of an instinctive desire for vitamines. Children would not suffer from eating fruit to excess if they were able to obtain it more frequently.

The child wants fat, and prefers butter, which is not free from germs, to margarine, a vegetable fat, highly commended by the manufacturers for its purity and cheapness. Evidence has been forthcoming to prove that the child, guided by his likes and dislikes, is right; that the economists, impressed by heat-values, freedom from germs, and cheapness, were wrong. During the submarine blockade in 1917 the Danes, in order to export more butter, gave margarine to their children, especially those of the poorer classes; the result was under-growth, failure of nutrition, and disease. When, however, the butter was rationed and sold at a low price to the poor these defects were cured.

It is impossible within the space of this chapter to attempt an adequate survey of the agreement between the results of applied physiology and the theory of evolution, but a few more examples may be given.

The open-air treatment of children suffering from tuberculosis has demonstrated that they benefit by a return to more primitive conditions, and, adapted by gradual exposure in the open air to sun and wind, heat and cold, can live a healthier and happier life.

Muscular exercise, either as manual labour or play in the open air, is a primitive need. The natural method of physical training is by trial and error, the development of the personal equation and style by practice, not by a system of drill which aims at uniformity, or lectures on the theory of how the work of the muscles should be performed. Work paced by machinery must ever be bad from the physiological point of view; compensation must be sought in a reduction of the hours of toil and more leisure for sport and recreation. The healthy man seeks and enjoys work as well as pay, for the dole without work results only in discontent, degeneration, and loss of skill. Horses are not only fed but exercised also when their masters have no work for them to do; men are governed by politicians who care little for the teachings of biology.

Lastly and briefly the question of mate and family will be considered, for it is too frequently one of the tragedies of civilization. Reproduction is the fundamental characteristic of life; repression and the failure to recognize physiological needs have degraded man below the beasts of the field; the so-called " morality of the farm-yard " is at least physiological, whereas in many cases the conventional morality of man is pathological, a curse to the individuals concerned and to the race.

The modern crusade of " birth control ", supported though it be by some biologists, is not based on biological principles, or the theory of evolution. It involves the view that the environment is more potent than the stock; it ignores the value of the struggle for existence and the survival of the fit. It is no evidence of self-control, sacrifice, and a yearning for the higher life, but a desire for luxury and a loss of belief in the capacity of the offspring. Its practice degrades woman both physically and morally, for the production and rearing of

children will always be the biological test of her womanhood and her greatest service to the race.

Birth control may be but a temporary example of adaptation, for degeneration is at times an easier means of adaptation than a virile struggle for existence. It may be even more: a blessing in disguise, a means of elimination of types in whom physiological processes are inadequately balanced.

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CHAPTER VIII

Anthropology

Charles Darwin and the Evolution of Man

The general acceptance by modern biologists of the fact that " man is the modified descendant of some pre-existing form " (Darwin) can be truly attributed to the work of Charles Darwin. The idea of man's descent from a long line of vertebrate ancestors is much older than Darwin, for as he himself points out in the " Historical Sketch " in the later editions of his *Origin of Species*, Lamarck (in works published in 1801, 1809, and 1815) " upholds the doctrine that all species, including man, are descended from other species ". Moreover, he has stated elsewhere (in a letter to Lyell in March, 1863) that " Plato, Buffon, my grandfather [Erasmus Darwin], before Lamarck and others, propounded the *obvious* view that if species were not created separately they must have descended from other species ". But if Charles Darwin was not responsible for originating the idea of man's descent the merit is certainly his of having convinced thinking men of its truth, and of collecting and presenting the evidence in substantiation of its reality in such a way as to force honest men to face the real issue.

One must, however, clearly distinguish between Darwin's demonstration of the evolution of man and the hypothesis put forward by him in the attempt to explain the process of evolution. The latter is still a matter of controversy and is likely to remain so for a very long time. But the doubt concerning the validity of his hypothesis of natural selection must

not be permitted to obscure the fact that Darwin is to be ranked with Copernicus, Galileo, Newton, and Harvey as a man who created a vast revolution in thought. His works *The Origin of Species* (1859) and *The Descent of Man* (1871) will ever remain classics in the history of science, which deserve to be more closely studied to-day than unfortunately is the case.

In the first edition of *The Origin of Species* (p. 488) he makes this interesting statement: " In the distant future I see open fields for far more important researches. Psychology will be based on a new foundation, that of the necessary acquirement of each mental power and capacity by gradation. Light will be thrown on the origin of man and his history." The last sentence is important as evidence that in 1859 Darwin had clearly in mind the application of his theory to the origin of the human family, and that *The Descent of Man* was not merely an afterthought twelve years later. The rest of the quotation is of special interest at the present moment when Darwin's vision of the " open fields " is being realized. For the progress of science is now opening the way, as I have recently attempted to show in *Essays on the Evolution of Man* (Oxford University Press, 1924), for the interpretation of the evolution of intelligence as the essential factor in the emergence of the qualities pre-eminently distinctive of the human family.

The Evidence of Evolution

The evidence upon which Darwin relied to establish his case for the reality of man's descent was, in the first place, the close resemblance of the structure of the human body to that of the higher apes commonly known as anthropoid. This argument had been put forward in a tentative way by several anatomists in the eighteenth century, and especially by Charles White, who submitted a series of memoirs on the subject to the Literary and Philosophical Society of Manchester in 1795, which were subsequently published as a treatise with the title *An Account of the Regular Gradation in Man and in Different Animals and Vegetables from the Former to the Latter* (London, 1799). Darwin claimed that the similarities were too close to

be explained in any other way than by a community of origin. In corroboration of this he urged three other considerations. First, the survival in man of a number of useless vestigial structures representing features of other animals which were an active and useful part of their economy. Secondly, the facts of embryology, namely that the human embryo in the course of its developmental history passed through a series of phases presenting a very much closer likeness to those of other mammals (and in fact vertebrates in general) than even the anatomy of the adult animals revealed. Thirdly, the animals (apes and monkeys) that presented the closest structural resemblance to human beings also revealed similarities in behaviour, in functional reactions, and in greater liability to human diseases than other creatures. The close genetic connection of man with the apes was thus demonstrated by identities of structure, function, and development.

The evidence relating to these elements of proof collected by Darwin himself was amplified and expounded by Huxley [1] and Haeckel [2] during the two decades after 1859, and the fact was definitely established that man was undoubtedly linked by the closest bonds of genetic affinity—the descent from a common line of ancestors—to the apes and other members of the mammalian order of Primates.

Fossil Remains of Man

At the time when Darwin's work was accomplished, practically nothing was known of one element of proof that looms very large at the present time in any exposition of the fact of man's evolution. I refer to the extinct members of the human family, whose former existence has been made known to us by the discovery of a series of fossilized remains since 1857. Darwin was aware that the lack of such evidence provided his critics with a useful weapon of attack; but he was able to claim that " the high antiquity of man has recently been demonstrated by the labours of a host of eminent men, beginning with

[1] *Man's Place in Nature*, and a series of other essays afterwards published in the volume *Darwiniana*. [2] *Natürliche Schöpfungsgeschichte*.

M. Boucher de Perthes ". The distinguished French archæologist had been striving for more than twenty years, in the face of tremendous opposition, to convince his colleagues that the flint implements found by him in the neighbourhood of Abbeville were made by men in extremely ancient times. His claims were met by little more than contempt and ridicule until, in the year of the publication of *The Origin of Species*, a group of English men of science, Falconer, Prestwich, Evans, Flower, and Lyell, turned the scale in favour of Boucher de Perthes by declaring their conviction that he had really discovered tools made by men who lived in the remote ages when elephants, cave bears, sabre-toothed tigers, and a host of other now extinct animals roamed in France. Since then fossilized remains of extinct members of the human family of bizarre types, differing in species, and in some cases even in genus, from existing races of men have come to light in Europe, in Java, and in Rhodesia, throwing back the certain history of the human family to the very commencement of the Pleistocene Period or even into the Pliocene.

Thus this important lacuna in the story told by Darwin has been filled in the sense that the remote antiquity of man—a matter of millions of years—has now been definitely established.

Fossil Apes

But another argument was brought against Darwin's view, the force of which new discoveries since his time have also shattered. In *The Descent of Man* he says: " The great break in the organic chain between man and his nearest allies, which cannot be bridged over by any extinct or living species, has often been advanced as a grave objection to the belief that man is descended from some lower form ". But at the time when he was writing the science that Serres in 1853 had already dubbed " Human Palæontology " was already developing under the guidance of Edouard Lartet. A brilliant account of the history of this movement has been given by Marcellin Boule in his book called in the English translation *Fossil Men* (Edinburgh,

1923). Lartet found in fossil beds of the Mid-Tertiary Period at Sansan the remains of an anthropoid ape (which he named *Pliopithecus*) akin to the gibbons that still exist in south-eastern Asia and the Malay Archipelago. The full significance of this event has been admirably explained in Boule's treatise, from which I quote. "P. Fischer points out the importance of this discovery from the point of view of the question of fossil man: Cuvier, in an enlightened and needful criticism of the so-called bone-remains of man and of contemporary monkeys of extinct species, exposed their lack of authenticity. He accordingly inferred that monkey and man were late in appearing. 'What astonishes me,' he said, 'is that, amongst all these mammals, the majority of which have at the present day congeners in warm regions, there is not a single quadrumana; and also that there has been found not a single bone, not a single tooth of a monkey, even of any extinct species. Neither is there any man: all the bones of our species which have been collected along with those I have referred to were present by accident.'

"In thus associating the date of man's appearance with that of monkeys," Fischer continues, "Cuvier prepared the way for the great reception accorded to the discovery of the Sansan ape [*Pliopithecus*], and it could be foreseen that the discovery of a fossil ape would be followed by that of fossil man."

The insight of Étienne Geoffroy Saint-Hilaire did not err. Cuvier's distinguished adversary had pointed out "the important bearing on natural philosophy" of Lartet's discovery, destined "to inaugurate a new era of knowledge relating to human life". In 1845 Lartet boldly admitted the possibility of the existence of man in Tertiary times, a presentiment, as Boule expresses it, of the part he was destined to play later on in 1860 in the scientific discussions as to the coexistence of man and the large Quaternary mammals. But before this he had made the important discovery of the fossil remains of a hitherto unknown anthropoid ape which (in 1856) he called *Dryopithecus*. It was a creature as big as a chimpanzee, to which and the gorilla it was clearly akin. Since then it has come to be

regarded as a rather aberrant if primitive anthropoid, not very closely related to the human family; but this extinct genus has now assumed a new interest and importance since William K. Gregory's demonstration (1924) of its nearer affinity to man.

The Discoveries in 1911

Important discoveries of the fossil remains of anthropoid apes were made by Pilgrim in 1911, which revealed that in the Miocene Period Northern India (the region of the Sivalik Hills) was the home of a great variety of anthropoids, including forms that seem to have been the ancestors of the chimpanzee, the gorilla, and the human family. In the same year fossils found in the Egyptian Fayoum revealed the fact that soon after the close of the Eocene Period diminutive representatives of the tailed monkeys of the Old World as well as of the anthropoid apes had already made their appearance. Numerous discoveries of the fossilized remains of yet more primitive members of the order Primates in southern France and in America have made it practically certain that monkeys were originally evolved in North America, whence in Eocene times some of them wandered across a land-bridge, which at that remote epoch linked America to Europe. The discovery of these fragmentary remains of early Primates has thus in some measure repaired what Darwin half a century ago called " the great break in the organic chain between man and his nearest allies ".

The Affinities of Apes and Men

The total result of these new discoveries of the fossilized remains of primitive apes and men is to afford strong corroboration to the claims put forward by Charles Darwin before they were made. Reading anew Darwin's classical works in the light of this fresh information, one cannot fail to be impressed with the clear vision and calm judgment of the man who converted the world to an appreciation of the reality of evolution.

Since his time intensive studies in comparative anatomy

and physiology, in embryology and palæontology, in the biological reactions of blood and the relative immunity of different animals from various infective diseases have each of them added their quota to the demonstration of man's kinship with the apes, and have given precision to inquiries regarding the exact line of his descent.

Much confusion has arisen from categorical statements regarding man's affinities with the apes. When the patent fact is expressed in words to the effect that man has not sprung from a gorilla or a chimpanzee, many people have hastily jumped to the conclusion that such an expression of opinion implies the elimination of a simian stage from man's ancestry. Whereas in most cases no such implication was intended. The palæontological evidence suggests that the ancestors of man and the gorilla must have begun to differentiate the one from the other at least as far back as the beginning of the Miocene Period, perhaps millions of years ago; but the immediate progeny of these respective lines of descent were not men and gorillas, but merely the simian forms whose ultimate descendants were destined to acquire the traits distinctive of the human family and the genus *Gorilla* respectively. Man is thus clearly not descended from a gorilla, but it is quite certain that both were derived from a common but very remote ancestry, which was definitely simian. There are, however, still a few zoologists who deny that man had a simian ancestry, and claim that the apes and men arose independently from more primitive " half-apes ", like the little Spectral Tarsier that lives in Borneo, Java, and the Philippines.

The Anthropoid Apes

But the facts of comparative anatomy and embryology, and the definite proofs of kinship afforded by the reactions of the blood, make it certain that the human family was derived from one of the anthropoid apes. While the tendency is to push back in time the cleavage between the ancestors of man and of the apes respectively, on the ground that the human family retains certain primitive characters which have been

lost by specialization in the apes, this must not be allowed to blind us to the fact of man's closer affinity to African anthropoids, the gorilla and the chimpanzee, than to those of the Malayan region, the orang and the gibbon. In fact it can confidently be assumed that the ancestors of the human family were sprung from a stem common to the ancestry of the gorilla-chimpanzee stock, after the ancestors of the orang and the gibbon had begun to differentiate from the still more primitive anthropoids.

The most primitive and smallest of the living anthropoid apes is the gibbon, which is now restricted to south-eastern Asia and the Malay Archipelago; but in Miocene times it ranged as far as Western Europe. Reference has already been made to the discovery of a fossil gibbon (*Pliopithecus*) by Lartet in France more than eighty years ago. The gibbon can be regarded as the survival of an early type of anthropoid which has retained many of its primitive features. As some of these traits also persist in man it has been erroneously assumed by some anatomists that the gibbon shows closer affinities to the human family than the other anthropoids; but it should be remembered that the giant anthropoids underwent a high degree of specialization in the process of transformation from a primitive ape into the forms which we know as the orang, chimpanzee, and gorilla respectively. Man's ancestors did not undergo the same kind of specialization, so that in the human family certain primitive features are retained which the giant anthropoids have lost. Failure to recognize the true significance of these facts is the explanation of the claims put forward by certain writers for a closer affinity between man and the gibbon, or in other cases with the primitive South American monkeys, or even with a still more ancient and primitive creature, the "half-ape" tarsier. Man's ancestors certainly advanced to the stage of the giant anthropoids (in the Miocene or possibly even in the Oligocene Period) before distinctive specializations of structure and function produced the orang, the chimpanzee, the gorilla, and man respectively from a common stock.

The Early Primates

The gibbon itself or its Miocene ancestor (*Pliopithecus*) can be regarded as the overgrown and somewhat modified descendant of the diminutive anthropoid *Propliopithecus*, the fossilized teeth and jaw of which were found in 1911 in the Oligocene beds of the Egyptian Fayoum in association with the remains of a small monkey (*Parapithecus*), representing an ancestral type of the tailed monkeys of the Old World. It can be confidently inferred that the small anthropoid was evolved at the close of the Eocene period from a tailed ancestor akin to *Parapithecus*, and that these earliest monkeys to arrive in the Old World were the descendants of forms which had recently come from America by a transatlantic land-bridge. It can be assumed also that the American ancestors were themselves very primitive monkeys, in most respects akin to those which still survive in South America with relatively slight changes in structure. Moreover it can be regarded as certain that these earliest monkeys originated during the Eocene Period from small tarsioids (closely akin to the tarsier still living in Borneo), whose fossilized remains have been found in Wyoming, in association with fossil lemurs and tree-shrews, which probably represent the survivors of two still earlier stages in man's pedigree, which takes it back by easy gradations almost to the beginning of the Age of Mammals.

Vision and Man's Evolution

In my *Essays on the Evolution of Man* I have explained more fully how this pedigree has been reconstituted, and the reasons for the confident claim for the essential accuracy of this scheme of man's family tree. But it will suffice here to call particular attention to the fact that the conclusions which the increase of our information in recent times has forced upon us are in remarkably close agreement with those adumbrated by Darwin and Huxley. In this sense one can claim that the latest phase of this argument is really a return to Darwinism. The ancestors of the human family are, of course, all extinct; but once the

hypothetical pedigree is restored, it becomes possible to select a series of living animals which have preserved (necessarily of course with some modifications) for us to examine the nearest possible approximation to the various phases through which man's forbears passed in the course of their evolution. By comparing such a series it is possible to obtain some definite conception of the nature of the changes effected at each stage in the process of transformation which gradually converted the descendants of the most primitive type of mammal into a human being. Such inquiries reveal that the two conditions essential for the continuous development of the brain in such a way as to make possible the attainment of the high powers of intelligence distinctive of man are (*a*) the cultivation of vision as the guiding sense (*b*) in mammals whose limbs have not been specialized for some particular function. For example, the hoof of an ungulate, the claw of a carnivore, the flipper of a seal, the wing of a bat are examples of specialization which make it impossible for the limbs in question to be adapted for other purposes. The lack of specialization in the hands and feet of man's ancestors conferred upon them a plasticity and an adaptability to enable them to become the instruments for performing acts of increasing degrees of skill, and a more and more sensitive tactile discrimination, as the brain acquired the ability to make possible such complicated actions and feelings.

The emergence of the distinctive attributes of mankind was due primarily to the close co-operation of eye and hand in an animal with a brain fitted to develop these possibilities to the utmost.

Evolution and Language

The acceptance of the principle of organic evolution exercised a profound influence on all kinds of non-biological studies; and workers in many domains of inquiry began to apply the conception of evolution to their own materials, and employ the technical terms that had been devised with special reference to biological phenomena.

In his valuable little book entitled *History of Biology*

(1911), L. C. Miall enumerates some of the effects of this influence. " Bagehot has applied Darwinian principles to the interpretation of history and politics. Philologists recognize a process very like that of natural selection in the modification of words. The usages of language are inherited from generation to generation; one idiom competes with another, that persisting which best suits the temper or convenience of the nation. Philology has, like zoology, its chains of descent, its breeds or dialects, its species or languages, its fossils (dead languages), its dominant and declining forms, its vestiges (such as letters, still retained, though no longer sounded)." And he proceeds to indicate its influence in psychology, sociology, and comparative religion.

The analogy between these linguistic phenomena and organic evolution, when expounded in this logical way by a biologist of clear insight, is real and illuminating. The derivation of one language, say of the Indo-European group, from the same source as another is not denied by anyone, and the terminology of biology is therefore not inappropriate when applied to the history of languages, provided that the analogies are not pushed too far. In particular the study of language illustrates very clearly the process of wearing-down or degradation, as well as of actual loss, which is a conspicuous feature of biological evolution, but has been lost sight of by those who use the phraseology of evolution in ethnology, as we shall have occasion to see in the following pages.

The study of language, however, became involved in anthropological controversy at an early period by the confusion of speech and race. Philologists too hastily assumed that because Sanskrit, Iranian, Greek, Latin, German, and Celtic languages were proved to be derived from a common parentage there was therefore a community of race also. At the time when the controversies concerning evolution were raging, Max Müller infused fresh life into this fallacy by inventing the term "Aryan", not merely for the Indo-European language, but also for a hypothetical race to include the people who spoke it. But as early as 1853 he recanted of his error.

One effect of these intensive studies of language was to emphasize the principle of the diffusion of myths from one centre. But Max Müller's undue insistence on the importance of the Asiatic cradle and the fantastic way in which he exploited his hypothesis that myths were essentially due to what he called " a disease of language ", brought ridicule upon his speculations, in the course of which a brilliant satirist, using Müller's methods of argument and phraseology, proved that Max Müller himself was a sun-myth!

" Evolution " and Culture

One unfortunate result of this exposure of the fallacies of his method was the repression of the very important evidence languages provide of the diffusion of culture. In this essay, however, I am concerned with the influence of the idea of evolution in anthropology, and have merely referred to philology in so far as it affects the study of man.

Herbert Spencer attempted to apply the principles of psychology and the conceptions of biological evolution to the social organism in the attempt to create a science of sociology.

But the most profound influence was exerted as the outcome of the unfortunate attempt to apply ideas of evolution to cultural anthropology. I have called this movement unfortunate, because the ethnologists who began to apply biological terms in their speculations fifty years ago did not take the trouble to use them correctly. They used the term " evolution ", not in the biological sense as the derivation of a series of different organisms from a common ancestry, but for a speculation that is the very antithesis of the meaning associated with this word by the zoologist and botanist. It was employed by the ethnologists to express the idea of independence of origin, the growth of analogous customs and beliefs *without* any community of origin or genetic relationship of any sort the one with the other. In other words the meaning the ethnologist meant to convey by the word evolution is what the biologist refers to as the " claim for spontaneous generation ".

When the palæontologists discovered the fossilized remains of camels in America they did not claim that they were spontaneously generated there in complete independence of the Asiatic camels. They confidently assumed that the camel was evolved once, and once only, and that the American and the Asiatic creatures were derived from the same parentage. The problem which the biologist set himself to solve was not this self-evident fact of a common ancestry, but the nature and origin of the ancestors, their area of characterization, and their migrations in America and Asia. But the ethnologist does not hesitate to claim that forms of culture, in their own way at least as complex and distinctive in structure as the anatomy of the camel is, grew up quite independently in different areas by a process of "spontaneous generation" which they call evolution, although the claim involved is the very negation of what the biologist understands by evolution.

The Glamour of a Fashionable Phrase

Although the use of the word evolution in ethnology is not half a century old, the idea to which this error in terminology was unhappily applied is much older. It can in fact be traced back as early as the eighteenth century and perhaps earlier still. But when it assumed the false label "evolution" it acquired the glamour of a fashionable phrase and thereby enjoyed an immunity from criticism. The idea of the independent development of culture thus gradually hardened into a rigid dogma. For the last four decades this has been respected by the great majority of ethnologists with quasi-theological fervour as a doctrine which it is almost sacrilegious to question. Even so recently as this winter, a few months after my book of *Essays on the Evolution of Man* was published, some of my colleagues have been proclaiming in university lectures that I am opposed to the idea of evolution, solely because for ten years I have been repeatedly calling attention to the misuse of the word by many ethnologists! I have repeatedly called attention to the fallacy involved in the misapplication of this technical term because it has dominated the history of ethno-

logy for nearly half a century. Much of the support for the idea of independent development of custom and belief has come from the widespread conviction that the use of so fashionable a word must connote scientific orthodoxy. Moreover, the opposition that has arisen in Germany against such orthodoxy has been influenced if not mainly inspired by a theological bias against the idea of evolution. Graebner and his school seem to have imagined that in contesting the principles called " evolutionary " in ethnology they were fighting against the English doctrine of evolution!

Although this divergence of opinion did not become a serious test of ethnological orthodoxy until the eighties of last century, it was already more than a century old at that time.

The "Fall of Man" and the Degradation of Culture

" So long as it was universally believed that man came into existence by a special act of creation, and owed his diversity of speech and custom to the miracle of Babel, there was little scope for a science of ethnology. It was generally held in the past that the more backward peoples of the earth, or rather those whom we regard as backward because they are different from ourselves, were so because they had degenerated from the state in which they were created."[1]

I do not think it is even now fully recognized how far-reaching has been the influence of the Biblical teaching regarding the " Fall of Man " upon anthropological theory. Its positive effects are generally recognized; how it hindered the adoption of the theory of evolution, and distorted the history of civilization, as Archbishop Whately and the Duke of Argyll did, by claiming that the lack of culture among many savage peoples is to be explained as the result of a degeneration and loss of civilization, which primeval man is supposed to have enjoyed, have been set forth with fullness and impartiality by Andrew Dickson White, formerly President of Yale University,

[1] Rivers, *Psychology and Politics*, 1923, p. 110.

in his book *A History of the Warfare of Science with Theology.*[1] But neither White nor, so far as I am aware, any other writer has called attention to the negative effects of this controversy. As the result of the overzealous refutation of Archbishop Whately's claims, ethnologists took up an attitude that has had a most misleading influence on the interpretation of the facts ever since. Thus, when he urged that " no community ever did or ever can emerge unassisted by external helps from a state of utter barbarism into anything that can be called civilization ", the ethnologists went to the other extreme and claimed that practically every people that had any culture did evolve it themselves " unassisted by external helps ". Moreover, they invented the argument that useful arts once acquired would not be lost, a most fallacious claim which wrought untold confusion in anthropological discussion, until Dr. Rivers, in 1912, exposed the error and its implications. But one of the most profound effects of the controversy concerning the doctrine of the Fall of Man was to eliminate from ethnological argument any adequate recognition of the principle of degradation of culture, which has always played and is still playing a very obtrusive part in the history of civilization. The importance of this factor has recently been emphasized by W. J. Perry in *The Children of the Sun*; but the writings of Sir Edward Tylor reveal the deep significance formerly accorded to the fact of the degeneration of culture before the theological discussions that followed the publication of Charles Darwin's works brought about so fateful a repression.

The " Lost Ten Tribes " and Atlantis

So long as people relied upon the Biblical account of the origin and migrations of the human family, it is easy to understand why, in the course of their speculations concerning the similarities and diversities of human culture, they should ascribe the similarities to such dispersals as tend to follow the great catastrophes of human history, especially when the

[1] See especially Chapter VIII, *The " Fall of Man " and Anthropology*, and Chapter IX, *The " Fall of Man " and Ethnology.*

elements of culture in question were such as might be ascribed to the dispersal of the Jews. Hence the frequent references to the widespread influence of the lost Ten Tribes was, in the then state of the subject, a legitimate view for which it was even possible to provide some evidence of a plausible kind.

Thus when the Spaniards discovered the New World they were amazed to discover many practices and beliefs that were not known to them except in the Biblical record; and it is not surprising that they explained the strangely exotic civilizations of Mexico and Peru as evidence of the work of the lost Ten Tribes. In the appendix to his *Conquest of Mexico* (1843) Prescott has given a very instructive summary of this episode. In the sixteenth century Bernal Diaz attributed to the Jews the wonderful buildings he saw in Yucatan; according to Cogolludo, writing a century later, the Spaniards believed that the Phœnicians or Carthaginians were responsible for them. But the most remarkable work of all was the treatise (1831–48) upon which Lord Kingsborough lavished a fortune in the misguided attempt to demonstrate that the "Aztecs had a clear knowledge of the Old Testament, and most probably of the New, though somewhat corrupted by time and hieroglyphics".[1] From time to time since then numerous other writers have issued books setting forth this claim. But an even more popular variant is the exploitation of Plato's story of Atlantis as the device by which the civilization of the Ancient East was transferred to the New World. The writings of such amateur ethnologists, commonly branded as "cranks", are not utterly devoid of interest. For they reveal the fact that men untrained in scientific method often appreciate patent facts calling for explanation, which the more orthodox scholar does not give. The amazing coincidences in the arbitrary details of hundreds of strange customs and beliefs revealed in the earliest civilizations of Central America, Mexico, and Peru, when compared with contemporary or earlier evidence from Asia, call for something more satisfying in the way of explanation than the claims that the resemblances "may arise from

[1] *Antiquities of Mexico*, Vol. VI, p. 409.

no more than a common psychology ", and that " the evidence which we possess points rather to the undisturbed evolution of Mexican and Mayan civilization on American soil, and that civilization may therefore be regarded as in every sense American ".[1] It is not surprising that " the man in the street ", who is not to be deceived by such trivial evasions of a great issue, attempts to interpret in his own way the obvious fact that there must have been some sort of intimate contact between the Old World and the New ten centuries and more ago to explain the derivation of the strangely exotic elements of the Mayan, Aztec, pre-Inca, and Inca civilizations.

Dr. William Robertson's " History of America "

I have already referred to the circumstance that the dogma expressed in the catch-phrases " the similarity of the working of the human mind " and " the independent evolution of culture " did not acquire such quasi-theological authority, as it has now exercised for nearly half a century, until the general adoption of ideas of evolution and the misapplication of the term by ethnologists. But the speculation of so-called " psychic unity " has neither any real affinity nor logical connection with what the biologist understands by evolution. In fact, the view that civilization grew up sporadically and independently in different parts was already being formulated in the eighteenth century.

Towards the end of that century certain speculations regarding the interpretation of the facts of history began to find tangible expression in a form curiously like the so-called evolutionary theory in ethnology a century later. Thus the historian Dr. William Robertson, Principal of the University of Edinburgh, used these words in his book *The History of America* (1777, Book IV, Section vii): " Were we to trace back the ideas of other nations to that rude state in which history first presents them to our view, we should discover a surprising resemblance in their tenets and practices; and

[1] T. A. Joyce, *Mexican Archæology*, 1914, pp. 370 and 371.

should be convinced that, in similar circumstances, the faculties of the human mind hold nearly the same course in their progress, and arrive at almost the same conclusions."

Whether Robertson invented this phraseology himself or borrowed it from his predecessors I have not been able to discover; but there can be no doubt that the Scottish professor of history and Principal of Edinburgh University called the tune to which a century later many puppets were destined to dance. But for eighty years or more the idea of independent origin of culture only rarely found expression in Robertson's phraseology. Perhaps the most important incident that helped to bridge this period is the statement found in Hugh Miller's *Scenes and Legends* (1835, pp. 31–2), in which the famous geologist expresses the doctrine in his own way:

" I have seen in the museum of the Northern Institution (Inverness) a very complete collection of stone battle-axes, some of which have been formed little earlier than the last age by the rude natives of America and the South Sea Islands, while others, which have been dug out of the cairns and tumuli of our own country, bear witness to the unrecorded feuds and forgotten battle-fields of twenty centuries ago. I was a good deal struck by the resemblance which they bear to each other; a resemblance so complete, that the most practised eye can hardly distinguish between the weapons of the old Scot and the New Zealander. . . . Man in the savage state is the same animal everywhere, and his constructive powers, whether employed in the formation of a legendary story or of a battle-axe, seem to expatiate almost everywhere in the same rugged track of invention. For even the traditions of this first stage may be identified, like his weapons of war, all the world over."

This was written at a time when Lord Kingsborough's amazing work on the *Antiquities of Mexico* was appearing; and Miller's attempt to give a rational explanation of similarities of culture based upon direct observation was in a sense an expression of a protest against the absurd form given to theories of diffusion when based upon theological arguments. In his

book *Myths of Pre-Columbian America* Donald A. Mackenzie has collected the data relating to the period of Robertson and Hugh Miller, and has indicated how the phraseology of the latter was adopted by Daniel Wilson (1863) and Andrew Lang (1884). But there are reasons for supposing that the influence of Miller upon British ethnological speculation was in the main not direct, but was exerted by way of Germany, where in the middle of the nineteenth century Miller's writings exerted a considerable influence.

The Doctrine of "Psychic Unity"

The doctrine of "psychic unity" was developed by the German traveller and ethnologist Adolf Bastian in 1860: but it is to be regarded as the outcome of a tendency in German philosophy associated with the teaching of Herbart and the anthropologist Waitz. Bastian's speculations about the nature of thought in primitive peoples exerted little influence until Tylor, unfortunately departing from the sobriety of judgment that distinguished his *Early History of Mankind* (1865), plunged into speculations on the subject of "animism",[1] and incidentally stimulated an interest in so-called "independent evolution" and "psychic unity", which he adopted from Bastian, as the latter had done from the Scottish writers.

But if Bastian and Tylor were the more conspicuous instruments in effecting this change of attitude, it was the general trend of thought at the time when they wrote which made it possible for them to persuade a whole generation of ethnologists—from 1871 to 1911—to accept without serious protest views so utterly devoid of reason, and so definitely at variance with the common experience of mankind.

In his well-known treatise on *The Rise and Influence of Rationalism in Europe*, Lecky has given an illuminating account of the circumstances which led to "the revival of the sense of truth" as an outcome of the efforts of the secular philosophers of the seventeenth century, and insisted upon the fact

[1] *Primitive Culture*, 1871.

that "the decline of theological belief was a necessary antecedent of their success". The views put forward by Robertson in the eighteenth century can be truly regarded as one of the results of this emancipation from the complete dominance of theological restrictions. For once men admitted that the Mosaic account was not a complete record of the history of early civilization, that the world was not really created in the year 4004 B.C., and that the original language was not Hebrew, the way was open for men to search for fuller information on these subjects. But many other lines of inquiry were opened up when this new freedom from theological restraints was acquired; and the conflicts which raged for the century following the appearance of Robertson's *History of America* were not primarily concerned with the theologians or their arguments, even though these loomed very large, so much as with different groups of secular philosophers themselves. While Robertson and his followers were tentatively suggesting the possibility of the independent development of culture, von Humboldt was expounding the evidence on the other side suggesting the diffusion of culture and Lord Kingsborough the distorted theology of the wanderings of the lost Ten Tribes. But there were also developing new lines of argument destined in time to play an important part in bolstering up the false claims for so-called evolution of culture. Starting from von Humboldt's *Kosmos*, Karl Ritter wrote ten volumes (1822–59) on the relationship of geography to human history; and in 1859 Waitz wrote his well-known book in which he indulged in speculations upon the psychic life of mankind. The writings of Waitz and the influence of Herbart's philosophy seem to have shaped the theorizing of Bastian, which exerted so vast an influence upon the history of anthropology when Tylor adopted the speculation of "psychic unity". But at the time Waitz was writing his book (which was published in the same year as *The Origin of Species*), Buckle was preparing his *History of Civilization* (1857–61) to expound the effects of environment upon mankind. If all these trends of thought defeated their various aims by the exaggeration of their claims,

one cannot deny them far-reaching influence in the history of anthropological theory. Even to this day Buckle has a host of followers, extremists who try to explain all history by an appeal to geographical conditions; and did not Waitz and Bastian call the tune to which most ethnologists are still dancing? But I refer to them here rather to explain that already in 1859, before Darwin had raised the issue of evolution, the way was being prepared for the adoption of the views that were to be branded with the new label, wholly inappropriate though it was. For the problem whether there was an underlying unity in civilization, in other words, whether diffusion of culture had been going on ever since man emerged from what is usually called savagery, was being discussed from Robertson's time (1777) until the issue was thrown into the stormy arena of evolutionary controversy a century later.

American Civilization inspired by Asia

Robertson's suggestion in interpretation of the facts of early history was merely one of many attempts to solve a difficult problem by those historians whose vision was not limited by the Mosaic account. Early in the nineteenth century (1813) von Humboldt called attention to the remarkable similarities revealed in early American and Asiatic civilizations; and drew the conclusion that " if languages afford only feeble proofs of the ancient communications between the Old World and the New, the connection is revealed in an indubitable form by the cosmogonies, the monuments, the hieroglyphs, and the institutions of the peoples of America and of Asia ".

Thirty years later (in the Appendix to his *Conquest of Mexico*) Prescott added materially to the strength of the argument submitted by von Humboldt; for if he did not so freely admit his conviction that the case for the derivation of American civilization from Asia was established, his summary of the evidence for and against such an interpretation was so critical and impartial that it was difficult to doubt what his judgment was. Four years later, however, perhaps as the result of the sceptical attitude of the traveller Stephens, whose

account of the Central American antiquities was issued while *The Conquest of Mexico* was being published, Prescott took up a position of hostility (even if he would not admit the change of attitude) to the idea of the diffusion of culture. Thus in a note appended to *The Conquest of Peru* (1847) he curtly dismisses the matter as though it were a dangerous subject to meddle with:

"I have not thought it necessary to swell this Introduction by an inquiry into the origin of Peruvian civilization like that appended to the history of the Mexican. The Peruvian history doubtless suggests analogies with more than one nation in the East, some of which have been briefly adverted to in the preceding pages; although these analogies are adduced there not as evidence of a common origin, but as showing the coincidences which might naturally spring up among different nations under the same phase of civilization. Such coincidences are neither so numerous nor so striking as those afforded by the Aztec history. The correspondence presented by the astronomical science of the Mexicans is alone of more importance than all the rest. Yet the light of analogy, afforded by the institutions of the Incas, seems to point, as far as it goes, towards the same direction; and as the investigation could present but little substantially to confirm, and still less to confute, the views taken in the former disquisition, I have thought it best not to fatigue the reader with it."

I have quoted this in full to suggest the attitude that prevailed in the earlier half of the nineteenth century. This quotation avoids a dogmatic expression of opinion, but is clearly hostile to the idea of an Asiatic inspiration for American culture. But in his earlier book (1843) Prescott discussed the whole subject in great detail, and was clearly impressed with the strength of the evidence in favour of the influence of the Old World.

The Phase of Instability in Ethnological Opinion

The opinions of ethnologists in general at this time were in a very unstable condition, as they were swayed in one way

or the other by previous writings. At one time the extravagances of men like Lord Kingsborough inclined scholars to follow Robertson; at other times the strength of the actual evidence overwhelmed all respect for authorities or for theories. This state of uncertainty reigned until the publication of Darwin's *Descent of Man*, when under the leadership of Tylor the theory of " psychic unity " seemed to overwhelm the judgment of ethnologists and make them believe that such vague sophistry was the application of evolution to human affairs.

But before Tylor gave ethnology this false lead he wrote *The Early History of Mankind* (1865), in which he went farther than von Humboldt and Prescott in his claim for the reality of the influence of Eastern Asiatic civilization in America, a view to which he returned on two occasions (1878 and 1894) during the years when he was the champion of the doctrine that denied the reality of diffusion as the chief factor in explanation of cultural similarities. In my book *Elephants and Ethnologists* (1924, p. 34) I have given an account of this episode that redounds to Sir Edward Tylor's honesty and impartiality in the search for the truth.

The Early Believers in the Theory of Diffusion

Before the great reaction began to take effect under Tylor's leadership, many ethnologists were drawing conclusions from the evidence of customs and beliefs that were logical and consistent and more in harmony with the fundamental principle of evolution—the derivation from a common ancestry—than the so-called evolutionary doctrine. To quote Rivers:[1] " When the subject began to be studied about fifty years ago [this was written in 1919] by those trained in scientific methods, this line of thought was dominant, and the work of the writers of that time, such as Meadows Taylor (1868–9), Lane-Fox [Pitt Rivers] (1869–75), Fergusson (1872), Park Harrison (1872–3), and Miss Buckland (1874–9), was guided by the idea that civilized man had travelled [in early times] far over

[1] *Psychology and Politics*, p. 111.

the world, and that the similarities found in widely separated parts of the earth are the outcome of the diffusion of features of culture from some part of the world, the special conditions of which had led to their appearance and development."

The Use of the Term "Evolution" in Ethnology

But in the seventies and eighties of last century, when the use of the word evolution became fashionable, a host of men whose training had been literary rather than scientific rushed into the discussion of the history of civilization and used the biological term "evolution" without first discovering its true meaning. When they claimed that similar conditions might lead to the independent development of similar customs and beliefs, it never seems to have occurred to them to inquire in any of the cases they discussed whether the conditions were really similar. Nor have the upholders of the dogma of psychic unity ever offered any explanation of the fact that it is not unusual in different communities of the same race living under similar geographical conditions for one to possess many of the arts and crafts, as well as customs and beliefs, of the higher civilizations, which are completely lacking in their kinsmen of the other group. The "man in the street" who is not obsessed by any theory will at once say that one group acquired from immigrants certain elements of culture. But the orthodox ethnologist will deny this if there are no written documents to establish the fact of external influence.

For instance, in his account of the mythology of Oceania,[1] in which are collected a series of stories from Melanesia, Polynesia, &c., revealing many curious identities of eccentric incidents with those of Indonesia and America, Roland B. Dixon arrives at this general negation (in the last paragraph of his treatise):

"Into the question of the several curious resemblances between Oceanic and American mythology it is impossible to enter here. In large measure they contravene the rule just

[1] *The Mythology of All Races*, Vol. IX, 1916, p. 307.

emphasized, since there is as yet no unimpeachable evidence for migrations between Oceania and America or vice versa, or even for definite contact; and such data as there are involve us in little more than a series of paradoxes. Until such contact or migration has been clearly established, Oceanic mythology must be regarded as essentially of Oceanic growth, although considerable elements of Asiatic origin have entered into the complex. Its history rests on that of the series of ethnic waves which, proceeding from south-eastern Asia and its adjacent archipelagos, swept in intricate currents to the uttermost verge of Oceania, bringing to each group or islet in the whole vast area its own peculiar heritage of tradition and belief."

This is a typical example of the incoherent and illogical methods of modern ethnological writing. There is no logical nexus between the second and third sentences in this quotation, and the fourth flatly contradicts the other two. For if the cultural streams from Asia swept to " the uttermost verge of Oceania ", how can the derivation of the latter's culture from Asia be denied? Moreover, why refuse to admit that " the curious resemblances between Oceanic and American mythology " come within the scope of the diffusion " to the uttermost verge "? It seems to me that the last sentence in his book stultifies the trend of the whole work.

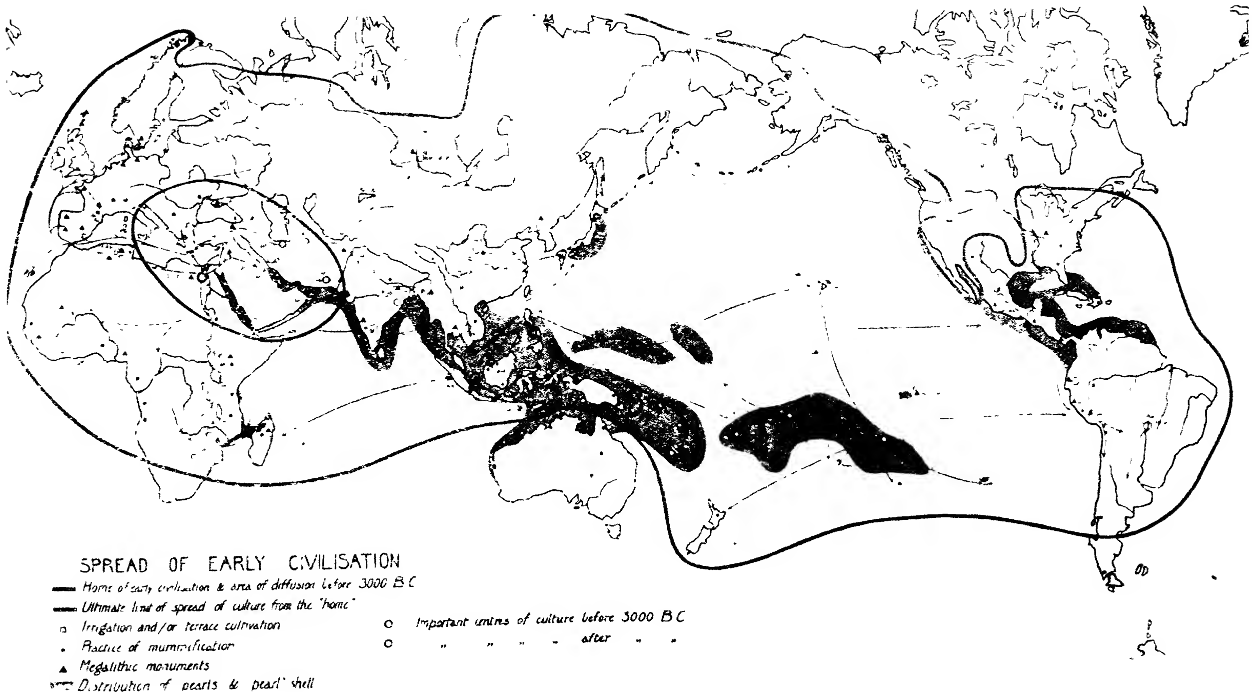
This quotation is a fair sample of the kind of argument that is being used in defence of the refusal to recognize the fact of the diffusion of culture in ancient times.

The effect of this attitude towards the interpretation of the history of civilization is so profound and far-reaching that it is desirable to examine it further and try to discover the causes of so strange an aberration. I have already called attention to the influence of the discussion regarding the doctrine of the Fall of Man in causing an almost complete repression of the factor of degradation of culture in the history of civilization and the invention of the false claim that useful arts are not lost. Once the reality of the fact is recognized that progress is the exception rather than the rule in the history

of human societies, the chief difficulty is eliminated that was responsible for the doctrine of " independent evolution ". For it was too hastily assumed that the idea of progress was the essential element in evolution, regardless of the fact that for every organism undergoing progressive change there are millions becoming more highly specialized, that is, less adaptable and less apt to progress. The real evolution of human culture is like the evolution of living creatures in that it requires an altogether exceptional set of circumstances to produce an advance in organization and more efficient achievement. Moreover, the identities of the action of evolution are revealed in every aspect of its operations. Every type of organism originated in one definite place from which it became diffused more or less widely in the world, at one time playing an important part in one continent, then perhaps in another, its activities waxing and waning with varying circumstances. In a similar way human arts and crafts, and customs and beliefs, were each of them evolved in one definite place, from which it was diffused far and wide and adopted or rejected by different peoples. No zoologist would for a moment believe that the camel was evolved independently in Asia and America, either from different ancestors or by spontaneous generation.

In the preceding paragraphs I have been endeavouring to make it clear that recognition of the spread of early civilization would bring the facts of ethnology into closer accord with organic evolution by revealing the derivation of similar customs and beliefs from a common source.

But the admission of the reality of such a process of cultural evolution imposes the necessity—in the light of the baneful influence of false analogies for the past half century—of not " overworking ", to use the late Lord Morley's phrase, the word and the idea of evolution. The whole history of the circumstances under which new inventions are made, the suspicion they arouse, and the dead weight of opposition to their adoption before they become diffused throughout the world, suggests that in early times of which we have no written records the same sort of things were happening. In other



Map of the World prepared by G. Elliot Smith and W. J. Perry to illustrate the history of civilization before the world-wide European Diffusion

words, the diffusion of culture is a fact the reality of which is established by our own daily experience and all the evidence of history.

The Psychology of Invention

When about fifty-five centuries ago some man in Egypt discovered how to extract copper from its ore, this accident would not have made much impression upon him if it had not been for the fact that he was already using a similar material (gold) for making amulets and bands. He did not instinctively realize that in extracting copper from its ore he was inaugurating one of the greatest revolutions in the history of civilization—the Age of Metals, which was destined to transform industry and add new terrors to warfare. To him it was merely a sort of gold useful for making amulets and jewellery; and no doubt it was adopted only very reluctantly as a poor substitute for the soft yellow metal that had acquired special sanctity as a divine substance, an elixir of life. After many decades it came to be realized that tools and weapons superior to those of stone could be made from copper; and later still that the metal could be shaped into a great variety of useful forms by casting.

All these events took scores of years, perhaps even centuries, to accomplish. The process involved a long series of accidents and numerous men of exceptional insight to appreciate the possibilities of each step in advance, and the courage and persistency to force their more stupid fellows to accept their discoveries. On the analogy of any invention of which we know the history in modern times, it is clear we must assume the discovery of copper and how to make tools of it was made once, and the knowledge of it was diffused throughout the world step by step from the place where the original discovery was made. But what was the mechanism of the process of diffusion?

From the very beginning of human occupation of the Nile Valley, so far as it is known at the present time, and several centuries before the discovery of the metal copper, men (and

especially women) were using the ore malachite as a cosmetic (perhaps as a green life-giving magic paint applied to their faces to protect them from danger to life). Are we to suppose that these early men (long before the invention of the art of building sea-going ships is known) imported their copper ore from Cyprus or elsewhere across the sea, as so many archæologists pretend? Not only are there no grounds for a theory so unlikely, but we know from the discovery of the actual mines in the Wady Alaqi in Nubia that the Egyptians got their malachite in Nubia, and that the scene of the early history of the discovery of copper and the invention of metal tools was in Egypt and Lower Nubia.

Early Colonization by the Egyptians

When the Egyptians came to realize the value of copper tools and the demand for the metal increased, they began (about 3500 B.C.) to search for fresh supplies of the ore in foreign lands, Sinai, Crete, Elam, Asia Minor. Wherever their prospectors discovered the ore they founded colonies to exploit it, and for centuries these small bands of Egyptians living in foreign lands and practising their own arts and crafts inoculated their foreign associates with certain of the elements of their own culture. For the most part no doubt it was the Egyptian immigrants themselves and their descendants who practised Egyptian arts and crafts in these foreign lands: but their influence in countries, which hitherto had been almost wholly uncultured, was the ferment that first produced the cultures distinctive of Sumer and Elam, of Crete and Syria.

So far the diffusion of culture thus roughly sketched is in many respects analogous to biological evolution, the derivation of a series of different species from a common ancestor. But the analogy is not complete. The shape assumed by an introduced culture depends upon the circumstances and the duration of the " inoculation ", and especially on the aptitude of the local population and their readiness to adopt certain elements or the whole of the alien culture. But after the

primary inoculation, when the mixture of immigrants and local people have built up a type of culture distinctive of the particular locality, the contact with other civilized communities becomes the fundamental condition of progress. Without such stimulation as intercourse brings there is prone to be stagnation and a degradation of culture; but intercourse that is effective involves an exchange of stimulating influences and a transformation of the culture.

False Analogies

In dealing with human beings who, in virtue of the acquisition of speech, are able to transmit information one to another and to hand on the fruits of experience to succeeding generations, a new state of affairs has arisen for which no exact parallel is found elsewhere. Hence the process involved in originating and diffusing knowledge and man's interpretation of it is something different from organic evolution. It is therefore dangerous and misleading to use such biological terms as "evolution" and "convergence", as so many writers are now doing, in reference to cultural history and to circumstances that are fundamentally distinct from those biological phenomena in reference to which the terms in question were devised.

The invention of arts and crafts and the shaping of customs and beliefs, are all of them distinctively human events for which no exact parallels are found in other living creatures; and it is therefore a hazardous proceeding to use superficial analogies that are so apt as to be dangerous, but in reality are so baseless as to be misleading.

The facts of the spread of culture and the circumstances that determine it are so completely within the range of the everyday experience of every man as not to need for their elucidation the dangerous practice of instituting analogies with biological processes of a totally different order.

Nor does the interpretation of the plain facts of the true history of civilization call for the invention of new and fantastic devices in psychology to make them plain.

The Psychological Factor

It must not be forgotten how large a part psychological speculation has played in the development of the ethnological doctrines criticized in this chapter. It was really a psychological hypothesis that Bastian put forward in 1860 to explain the facts of ethnology. If people widely scattered in remote parts of the world have essentially the same folk-lore and myths in association with similar customs and beliefs, perhaps the explanation may be an identity of primitive ideas, a sort of instinctive thinking of the same thoughts. This crude form of psychological explanation was not altogether surprising in a German philosopher in 1860, when the trend of psychological theory favoured such ideas. But it is less easy of understanding how a doctrine based upon such shallow reasoning could have been adopted by Tylor and the anthropological world as a whole. Yet the argument of psychic unity is still solemnly used, not merely by writers ignorant of psychology, but even by professed psychologists. Until his death Wundt was the leader of this school of thought in Germany. Even in a book dealing with instinct, in which the limitations of human instinctive actions are clearly defined, William M'Dougall refers to the survival, in Borneo, of the ancient Babylonian and Roman practices of hepatoscopy and reading of omens in the flight of birds as a striking instance of the similarity of the working of the human mind. But after ten years of criticism of such statements one hears very little of psychic unity at the present time.

Nevertheless the claims involved in this kind of psychological argument have not been entirely abandoned by ethnologists. They have merely been given a new veneer. As the "manifest content" of such statements was not susceptible of defence by the citation of ethnological facts, recourse is now being made to Freudian psychology and to the "latent meaning" of the evidence afforded by customs and beliefs of primitive peoples. The *Voelker-Gedanken* of Bastian's doctrine have now given place to the "typical symbols" of Freud.

Just as neurotic patients have dreams or phantasies of the waking life, which the psycho-analysts attempt to force into one common mould of wholly arbitrary symbolism, so Freud and certain ethnologists, who have somewhat precipitately accepted his wild speculations, assume that primitive people dream the same dreams and so devise the same myths as other peoples by a sort of instinctive process which they refuse to call instinct.

It is unnecessary to pay further attention to the claims of these writers that have no more relevance to the facts of savage life and thought than they have to serious psychology. The so-called "typical symbol" and the "typical dream" are certainly mythical. The symbolism of myths, like the symbolism of dreams, is based upon tradition—in one case the experience of the multitude of people concerned in devising and transmitting the story, in the other the individual experience of the individual. The ethnological value of myths lies partly in the evidence they afford of the diffusion of culture, and secondly in the light they shed upon early history and beliefs and the confusions that develop in the course of the age-long repetition of familiar tales.

Psychology as the Unifying Factor

The interpretation of ethnological material is essentially a problem in psychology, an analysis of the motives that impelled men to act in certain ways, and the reconstruction of the history of events. The realization of this fact establishes the link between the two branches of anthropological inquiry. For the primary aim of the study of the human evolution should be to discover how man's ancestors acquired these attributes that distinguish mankind from all other living creatures, in other words, the high powers of intelligence. The determination of the nature of the human mind, the factors of its emergence, its range and its limitations, and the way in which instinctive tendencies come more and more under the control of man's powers of discrimination and the results of experience—these are also the factors that will

in time enable us to interpret the facts of ethnology, the evolution of customs and beliefs, and the inner meaning of the history of civilization.

Psychology then is the unifying principle in the study of mankind.

In the earlier part of this chapter it was explained that the emergence of the distinctively human qualities of mind was made possible because in certain small generalized mammals the sense of vision acquired increasing influence in guiding the creature's behaviour. The fact that the limbs had not become specialized for a particular purpose but retained their primitive adaptability rendered it possible for them to become fashioned into the instruments for performing an increasingly complex series of skilled movements. The guidance of vision made possible the acquisition of such skill, and incidentally the use of the hands cultivated the sense of touch. But the stimulation of the animal's curiosity, which resulted from the enhancement of its visual powers, led it to handle objects and not only acquire skill and tactile discrimination, but also learn to appreciate the nature of things and events in the outside world.

The acquisition of the ability in increasing degree to appreciate the meaning of the world and its happenings, ultimately conferred the distinctively human powers of comprehension and of learning from experience. Not only so, but as these powers grew the tendency to act on the impulse of the appetites and instincts was subjected to the more powerful control of the intellect and personal experience. There is little to differentiate between man and the apes so far as the instincts and appetites are concerned. The great difference depends upon the enormously greater power of man to appreciate the significance of events and to control his instinctive tendencies in the light of his acquired knowledge.

Egypt the Cradle of Civilization

There is no longer any doubt that man is descended from a series of anthropoid apes whose Miocene forerunner was

also the ancestor of the gorilla and the chimpanzee. It is also certain that for a vast period of time—perhaps even millions of years—men lived upon the earth without attempting to devise any of the arts and crafts or customs and beliefs that form the constituent elements of civilization. But about sixty centuries ago a fortuitous concatenation of circumstances impelled men living in the Nile Valley to devise the practice of agriculture, and as one of the results of the settled mode of life, which mankind thus adopted for the first time in their career, civilization was gradually built up, and in course of time diffused throughout a great part of the world. Before 3000 B.C. Egyptian colonies planted the germs of the earliest civilization in Crete, Syria, Sumer, Elam, and elsewhere. Within the next millennium secondary diffusions from each of these centres carried variously modified types of culture to many new centres in Europe, Africa, and Asia, including India, Siberia, and China. In the next millennium there was a further diffusion into Indo-China, the Malay Archipelago, and Melanesia; and at about the beginning of the Christian era a widespread exploitation of Polynesia began, one of the ultimate effects of which was the transference across the Pacific Ocean to Peru, Central America, and Mexico of the germs of their civilization.

It is an unquestionable fact that there is a unity in the inspiration of civilization. The widespread diffusion of culture from the Ancient East, which eventually encircled the globe, did not begin much before 3000 B.C.

NOTE.—Since this chapter was written Professor Raymond A. Dart has announced the discovery of the Taungs skull, which provides tangible confirmation of Darwin's prediction in *The Descent of Man* (1871): "It is probable that Africa was formerly inhabited by extinct apes closely allied to the gorilla and chimpanzee; and as these two [genera] are now man's nearest allies, it is somewhat more probable that our early progenitors lived on the African continent than elsewhere."

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CHAPTER IX.

Mental Evolution

Darwin—Spencer—Wallace

It is now very generally believed that the mental powers of mankind are in some sense the product of a long course of evolution. This belief has been established among the general body of accepted teachings of science within the lifetime of men who are still active in adding to our knowledge. It was implied by the views on evolution of the animal world put forward by a few thinkers about the end of the eighteenth century. But it was not until the work of Darwin and Wallace had convinced the scientific world of the gradual evolution of the bodily forms of animals, and had shown that man's body could not be excepted from this great generalization, that the problem of the evolution of man's mental powers was seriously proposed. Charles Darwin did not shrink from this problem. With great courage he faced and accepted the implications of his theory, and turned his great powers of observation and generalization to the task of showing, not only that evolution of the mental powers has taken place, but also that those powers have played an active rôle in the process of evolution.

The great prestige of Darwin, resulting from the success of his theory of natural selection, secured serious consideration for the theory of mental evolution. It was accepted almost at once by T. H. Huxley and other leading biologists as a corollary of the general theory of organic evolution, and was enthusiastically expounded by them. About the same time, and indeed a little before Darwin had made clear this implication of the theory of evolution, Herbert Spencer had independently begun to teach the same doctrine as a part of the all-comprehensive theory of evolution to the development of

which his life was devoted. It must always remain one of the glories of English science that the theory of mental evolution was first given definite form and currency by the work of these two great men.

The theory of mental evolution, thus launched at the same time by a great philosopher and a great naturalist and upheld by them at the height of their fame and prestige, provoked at once an acute controversy. It was generally felt to be a most dangerous threat to much that had been accepted as fundamental in morals and religion. Many of those who were prepared to accept, or had readily accepted, the theory of evolution as applied to man's bodily structure, were acutely aware of the danger, and saw also, however imperfectly, the difficulties involved in the attempt to apply the theory to mind. A. R. Wallace, the co-author of the theory of evolution by natural selection, was one of these. He, like many others, compromised by accepting the theory of evolution as applied to the human body and rejecting it as applied to man's mind. While abandoning the doctrine of special creation of each species, so far as it concerned the animal world and the bodily structure of man, he continued to hold it for the mind or soul of man. And in this compromise he was followed by a host of those who were primarily concerned with the moral and religious implications of the theory, as well as by a considerable number of men of science.

The Dualistic Theory—Body and Soul

But the compromise was essentially unstable and difficult to defend. The attack upon it came from two powerful parties, working by very different methods. On the one hand the philosophers proper, or metaphysicians, for the most part found it untenable because it implied a radically dualistic view of human personality, the view that man is a temporary conjunction of two things of entirely different nature, the material body and an immaterial or spiritual entity, the mind or soul. This dualistic theory of human personality, which comes down from the earliest speculations of primitive men, was

first clearly formulated by Plato. Although Plato's great successor, Aristotle, had expressed on this question a doubtful and ambiguous opinion that gave rise to centuries of controversy among the Arabian and European philosophers and theologians, the dualistic theory became generally accepted by philosophy, by the Church, and by the popular mind, and held almost undisputed sway until the modern period. Descartes gives it a new and more definite formulation and anticipated the modern compromise by denying a soul to animals, while affirming for man the independent reality of his soul and the radically different natures of his interacting material body and immaterial inextended soul or mind.

But the clear formulation of these views by Descartes, acceptable as it was in the main to the Church and to the popular mind, led philosophers to examine the problem more closely and to bring out more clearly the difficulties inherent in it and the many objections to it. Spinoza and Leibniz led the way in rejecting the dualistic theory and in propounding alternatives. Since their time the dualistic theory, though it still has the support of reputable thinkers, has fallen more and more into disfavour with philosophers; and, by the time Darwin and Spencer launched the theory of mental evolution, it had ceased to be seriously entertained by the great majority of metaphysicians. The philosophers, then, who had ceased to distinguish mind, or soul, from body, found themselves, not without dismay in many cases, one supposes, committed to accept the theory of evolution as applied to man's mind by the overwhelming evidence of its truth as applied to his body, and could but give their general adhesion to Darwin and the naturalistic exponents of mental evolution.

Perhaps the influence of the metaphysicians upon the controversy was negative rather than positive. Such influence as they exerted favoured, in the main, the theory of mental evolution; not in virtue of any active support of it by them, but rather because, having rejected the dualistic view of human personality, they had nothing to oppose to Darwin's theory.

Mental Powers of Animals

More active support for the theory of mental evolution and a more aggressive attack upon the compromise position of Wallace came from another quarter. An immediate consequence of the formulation of the theory was a more active study of the mental life of animals and a quickening of interest in psychology in general, especially in comparative psychology. In this movement J. G. Romanes led the way, and was followed by many others. The question of primary interest which they sought to answer was—Are the mental powers of man so different, so distinct in nature, from those of the higher animals that it is impossible to imagine a gradual and continuous evolution of the latter into the former, comparable to and parallel to the continuous gradual evolution of man's bodily structure which Darwin's work had done so much to establish as accepted theory?

The controversy was very seriously hampered by the backward state of psychology and the confused condition of psychological terminology. Those who took their stand against mental evolution, giving a positive reply to the question defined above, usually insisted that man differed from the animals in his possession of " reason " and " conscience ". They were prepared to admit that animals may have " sentience " and " instinct " and even a little dose of " intelligence "; but they insisted that the human race is distinguished by the possession of reason and conscience in addition to those lower powers which it has in common with the animals; and further, they asserted that these two powers or faculties are peculiar and distinct, that no analogue or rudiment of them is present in any animal, no germ from which they might have been developed. To these two, many added a third distinctive function, namely, free will.

This contention was, however, very unsatisfactory. It could not be scientifically sustained; for it implied and was stated in terms of the " faculty psychology ": a form of psychology which explained our mental life by distinguishing

certain types of mental function and describing each such type of function as the work of a corresponding faculty; and this faculty psychology, although it had enjoyed a career of centuries, had long since been condemned as erroneous and misleading by common consent of philosophers and psychologists.

The opposition to the theory of mental evolution, which was in reality motived by fear lest the theory should prove destructive to moral values and subversive of religious beliefs, took its stand on untenable ground and was quickly overwhelmed by the thoroughgoing exponents of evolution.

Lamarckian Theory of Lapsed Intelligence

But worse was yet to come. Darwin and his earlier followers had been content to adopt the common-sense view that the mental processes of men and animals, their purposive intelligent strivings, are of real effect in the guidance of their bodily actions, and that they have played some real and important part in the evolutionary process. Thus Darwin himself (and in this respect Herbert Spencer was at one with him) maintained until the last the truth of the theory of Lamarck, the theory that the organism adapts itself to its environment by more or less intelligent and effective purposive striving, bringing about, in so doing, appropriate modifications of its bodily structure and functions, and that it transmits such modifications to its progeny. Especially it was maintained that the instinctive tendencies of animals had been gradually evolved in the race by the formation in this way of habits which were transmitted, with increasing perfection in successive generations, from parent to offspring. This was the widely accepted theory of " lapsed intelligence ".

So long as this Lamarckian theory of lapsed intelligence was acceptable, mind appeared to have played a leading rôle in the drama of evolution. And the distress of those who felt compelled by the arguments of the evolutionists to resign their belief in the special creation of each human soul was mitigated by the belief that, though the human mind could no longer be regarded as radically distinct in nature from the animal

mind, mind in general was secured in a position of dignity by the recognition of it as the creative agency that had, by its own efforts, effected both its own evolution and that of the body. For it was clear that the animal body is but a system of organs that subserves, in each species, the instincts of that species, and that, if the instincts are moulded and developed by purposive intelligent strivings, so also are their instruments, the bodily organs.

Attack on the Lamarckian Theory by Physiologists

But this comforting view, though widely accepted and stoutly defended by such champions as Samuel Butler and Wilhelm Wundt, was soon made the object of deadly attacks from two quarters. On the one hand, the physiologists of the nineteenth century had been pushing with considerable success the mechanistic explanations of bodily functions which Descartes had brought into fashion in the seventeenth century, and of which Harvey's explanation of the circulation of the blood was a triumphant example. They studied certain simple involuntary movements, such as the winking of the eye, and showed that such a movement might be explained as the mechanical effect of a sensory stimulus. For they traced the sensory nerve from the spot stimulated to the central nervous system, and showed that there it makes junction with the motor nerve which passes from the central nervous system to the muscle concerned in the production of the movement. Further, they showed that on stimulation of the sensitive spot a wave of physical change passes along this nervous path, inwards to the central nervous system and outwards from it to the muscle, inciting it to contract. Such a process, beginning with a sensory stimulus and ending in a muscular contraction, was called a " reflex action "; and it was pointed out that, although the action, such as the winking of the eyelid, might be very serviceable and timely, and, in that sense, purposive, it might properly be claimed as a purely physical series of events mechanistically determined.

Then came rapidly a further step in the argument. It was

shown that the whole nervous system, including the great brain of man, the so-called organ of mind, is constructed after the pattern of the reflex arc; it was contended that all its processes are of essentially the same nature as those of the reflex arc, the mere passing onward in the nerve fibres of physical processes initiated in sense-organs and issuing in the motor nerves that agitate the muscles. Thus all bodily movements, including all those that constitute the conduct of human beings, even the noblest actions and those that seem most clearly to be the issue of a true moral choice, were made to appear to be nothing more than complicated " reflex actions ".

From this it was but a step to the conclusion that what had been called conscious mental activity is an inert accompaniment of the reflex processes of the brain, an " epiphenomenon " as Huxley said, a phosphorescent glow that breaks out in the brain when it is traversed by currents of physical energy, a glow that illumines the world without influencing the course of its events, that renders us passive spectators and excites in us memory of the past and desire and the illusion that by our purposive striving, by our intelligent choice, by reasoned foresight, we can in some degree avoid that which is evil and hold fast to that which is good. But if intelligent foresight and purposive striving are powerless to influence the course of events, it follows that mind is a mere by-product of evolution and has played no part in the process.

Attack on the Lamarckian Theory by Weismann

The other attack came more suddenly and seemed even more crushingly destructive of the view which would assign to the intelligent purpose of organisms a leading rôle in organic evolution. Darwin and Spencer had assumed without serious questioning the truth of the Lamarckian theory, the reality of the transmission to offspring of the modifications acquired by organisms. In the last quarter of the nineteenth century, August Weismann launched his attack on this theory. He asserted the continuity of the germ-plasm; that is to say, he showed reason to believe that the germ-plasm, the repro-

ductive cell of any organism, is derived by simple fission from the similar cell of its parent and is not in any true sense a product of the complex organism by which it is carried; that the developed complex body of the organism is merely a vehicle by means of which the germ-plasm is sheltered, fed, and allowed to multiply and perpetuate itself from generation to generation. And Weismann supported this view by destructive criticism of all the evidence which had been held by Darwin and Spencer and biologists in general to justify the Lamarckian assumption. This attack, coinciding in time with the culmination of the attack from the side of the mechanistic physiologists, was so successful that within a few years the great majority of zoologists rejected the Lamarckian theory, and neo-Darwinism became the generally accepted doctrine.

Neo-Darwinism

Neo-Darwinism is Darwinism purified by the elimination of Lamarckism. It teaches that "selection" alone, or the principle of the survival of the fittest in the struggle for existence, is the sole principle of organic evolution. And the words "selection" and "struggle" as used in the neo-Darwinian formula are to be understood as metaphors only. Selection and struggle or striving are illusory. The process so described is to be understood in a purely mechanistic sense. The neo-Darwinian principle of evolution by natural selection is as applicable to the evolution of the chemical elements from some primordial substance as to the evolution of plants, animals, and men. There is no more scope for the operation of intelligent purpose in the one case than in the other. The course of evolution, both organic and inorganic, has been a mechanical process, a process strictly determined and in principle strictly predictable according to the laws of thermodynamics.

Thus the theory of the evolution of mind was established at the same time that the theory of evolution by, or through the agency of, mind was sapped and rejected. To those who accept these conclusions, and they include the majority of men

of science and many of the philosophers, it seems that the progress of science has destroyed the last stronghold of those who are reluctant to believe that mind and purpose are of no effect and that the universe and the whole history of its evolution can be interpreted in strictly mechanistic terms.

These conclusions are not accepted at the present time by all of those who are qualified to form an opinion. Some men of science and some philosophers still maintain that any such view, any view which represents mind as a wholly ineffective by-product of a mechanical evolution and purposive striving as an illusory appearance of a process that is strictly mechanical, is unacceptable; they assert that there must be some flaw in the reasoning or else in the premises of the argument that leads to so monstrous a view of the world, a view so destructive of all human aspirations and of all belief in the value of moral effort.

Before we consider what may be said in support of this remonstrance, we may with advantage return to set out concisely the evidence on which is founded the modern belief in the reality of mental evolution. I shall then set down the description of the course of mental evolution which the mechanistic theory implies. I shall make some brief critical examination of this view, and go on to sketch in outline a description more in harmony with sound psychology. Lastly, I shall review the suggestions made by contemporary thinkers towards a theory of the evolutionary process in which the reality of mental activity and the efficiency of reason and purpose are preserved.

The Evidence for Mental Evolution

That biological evolution has occurred, that the higher organisms have been gradually evolved from simpler forms through a period measured in millions of years, is now a well-established theory. It is in the highest degree improbable that any advance of science will seriously shake this theory; though it is conceivable that, with the decay of our civilization, the

theory may be rejected by the popular mind and the teaching of it be banned from our schools and universities. It is noteworthy that in America serious efforts in this direction are now being made. But, since it is the theory of mental evolution, rather than the general theory of biological and cosmic evolution, that is likely to be most strenuously attacked, it is well to review concisely the evidence and reasoning by which the former is supported. For it must be admitted that the theory of mental evolution is less securely founded than the general theory of evolution.

To many, perhaps most, of those who at the present day accept the theory of mental evolution, it seems to follow as an inevitable corollary from the general theory of evolution; yet the instance of A. R. Wallace illustrates the fact that the drawing of this corollary may seem unjustifiable to very competent biologists, and serves to remind us that the evidence for mental evolution requires to be independently examined.

The general theory of organic evolution rests on four main lines of evidence; (1) the evidence of comparative anatomy; (2) the evidence of embryology; (3) the evidence of palæontology; (4) the evidence of genetics, the experimental breeding of animals and plants. These evidences are set forth in other essays included in this volume and need not be recited or examined here. We may be content to note that these four lines of evidence, taken together, suffice to establish the theory for all who are capable of drawing a conclusion from a great mass of recorded facts.

The evidence in support of the theory of mental evolution is less complete and cogent in two ways. The evidence from comparative anatomy is paralleled by evidence from comparative psychology. The evidence from embryology is paralleled by the evidence from the study of the development of mental life in the child and in young animals. The evidence from palæontology is slighter and of less direct nature than the corresponding evidence for the general theory of evolution. The evidence from genetics is lacking or so slight as to be negligible. Let us, then, examine in turn these three lines of evidence.

Evidence from Comparative Psychology

Comparative psychology attempts to describe the mental life of men and animals from the comparative point of view. The attempt encounters at every point a difficulty unknown to the comparative anatomist, a difficulty which infects with some uncertainty all the data and every step of the argument. Each of us has direct acquaintance with mental activity only in his own person. He cannot perceive or in any way directly observe the mental activities of animals or of other men. He can only observe their bodily attitudes and movements, and must infer from these the nature of the mental processes that seem to find expression in such attitudes and movements. When we make such inference in respect of our fellow-men, especially the men most similar to ourselves in respect of descent and training, we may have fair confidence in our conclusions, though never complete confidence; and the more unlike ourselves is the man or animal whose mental processes we thus infer, the more questionable are our own conclusions.

The difficulty is all the greater by reason of the fact that even the observation of our own mental processes is very difficult and always woefully inadequate to reveal in full the nature of those processes. It follows that all our descriptions of the mental life of animals and of men of dissimilar types of descent and culture, being infected with this incompleteness and uncertainty, cannot compare with the descriptions of the anatomist as data for our comparative study.

In spite of these difficulties and weaknesses, comparative psychology does afford strong evidence for the theory of mental evolution. We find that, following back along the line of descent of man and the higher animals as indicated by biology, we meet with behaviour of successively simpler types implying simpler types of mental process, until at length we reach organisms whose structures and modes of behaviour are so remote from our own that the inference to their mental processes becomes extremely uncertain.

We find also that throughout this series there is nowhere

evidence of any great break of continuity; at no level or stage is there good ground for believing that any mental function of an entirely novel type is manifested. Rather at every stage the mental powers displayed seem to be such as we may suppose to have been developed by a further differentiation and specialization of mental powers displayed at the lower levels.

Man and the Lower Animals—Ideas—Reason—Will—Instinct

Two types of mental process have been widely held to mark some unbridgeable gap, some discontinuity, in the scale of mental powers. The one is " ideation ", the other, " reasoning ". It has been argued that the lower animals, though they may be capable of perceiving objects and of adapting their behaviour to such objects more or less intelligently, yet show no evidence of capacity to think of objects not at the moment presented to their senses. And some observers have held this to be true of all animals. This is what is meant by the denial of " ideation ", or of " ideas ", to animals. It is, however, an ill-grounded view. The behaviour of some of the higher animals, especially the apes, does very clearly imply such thinking of absent objects; they sometimes act with reference to such objects, as when an animal seeks its nest or home or lies in wait for unperceived prey.

The denial of reason, or the germ of reasoning power, to all animals is equally ill-based. Reasoning is the interplay of processes of judgment; and that some of the higher animals display behaviour that implies judgment is indisputable; and in some instances we seem to discern evidence of that interplay of judgment which leads to the anticipation of the future and is properly called " reasoning ".

Again, the psychologists of an earlier time accentuated the gap between men and animals by ascribing " instinct " to animals while denying it to man. And they made of " instinct " an all-sufficient principle of explanation of animal behaviour; while in a similar fashion they explained all human behaviour by the aid of two equally unanalysed principles, " reason "

and " will ". The more careful analyses of animal and human behaviour made in recent years have clearly shown the misleading nature of these assumptions. They have shown that while the instincts of animals play a predominant rôle in their lives, their operations are nevertheless modified and guided in various degrees by intelligent appreciation of the circumstances under which each instinct is brought into play. And they have shown equally clearly that, although in man the development of intellect and character profoundly modifies and masks the operation of instincts, yet his mind also is built up on a foundation of instincts, instincts which are essentially similar to those of the animals nearest to him in the biological scale.

Evidence from Comparative Anatomy

The evidence from comparative psychology receives strong support from comparative anatomy, especially the comparative study of the sense-organs and nervous system. These are admitted by all to be in some sense the special organs of mind. Modern research has shown that particular aspects of mental life are somehow bound up with special parts of the brain. It has been shown that various parts of the human brain are homologous in structure and function with corresponding parts of the brains of other vertebrates; and that the chief difference between the brain of man and those of the higher mammals is that in man the cerebral hemispheres, the parts of the brain last evolved in the vertebrate, are much larger and more complexly organized. In fact it has been shown that there obtains a close parallelism between the degree of development of the brain and that of the mental functions. Comparative study of brains shows that the brain has evolved through the superposition upon the primitive brain of the lowest vertebrate of new parts of higher function, parts which, without superseding the functions of the lower older parts, modify, control, and co-ordinate their operations. And comparative study of human and animal behaviour shows that the mental functions have been evolved in a similar

fashion, the later evolved functions being superimposed upon the more primitive and fundamental, modifying and controlling them, without abolishing or superseding them. In fact the parallel between the evolution of brain and the evolution of mental functions seems to be clearly made out, in general terms, as a rule without exceptions.

Evidence from Mental Life of the Child

The study of the mental life of the child affords evidence of mental evolution hardly less cogent than the evidence of bodily evolution brought by embryology; and it is of the same general nature. Embryology shows that the bodily organism of each one of us begins as a minute cell in which we can distinguish only relatively simple structure and functions; it shows that this cell gradually grows by multiplication and by differentiation of the parts of the growing man into the incredibly complex structure of the adult man; retracing in a general way, while so developing, the steps by which simple unicellular organisms have given rise, by evolution through millions of years, to the higher forms of life. In a closely parallel fashion, the study of the mental development of the human individual shows that the mental functions of the adult seem to be developed by a perfectly gradual process from some simplest rudiment of mentality, and that the course of this development retraces or recapitulates in a rough way the course of mental evolution indicated by comparative psychology. At no point in either scale, the scale of individual development or of racial evolution, can we find any evidence that would in the least justify us in saying: "At this point in the scale mind begins to manifest itself. Below this point there are no indications of mental life." We can only assert that, as we pass down the scale, in both cases the indications of mental life become fainter and less easily interpretable.

In the foregoing paragraph I wrote—"as we pass down the scale" advisedly. And here a question of method of some importance is raised. Many of those who have written upon mental evolution and comparative psychology begin their

study by looking for indications of mental life in the lowest organisms, and, failing to find any such indications of an indisputable kind, proceed to search the scale of life from below upwards. They then commonly fail to discern any certain indications of mental life until they arrive at the higher animals, perhaps the higher apes, or even man himself. Beginning with the plausible assumption that the lowly organism is merely a physico-chemical system all of whose processes are of the mechanistic type, they apply, implicitly, the principle of continuity, and, finding no sharp breach of continuity, they are predisposed to assume the validity of the mechanistic interpretation of the behaviour of successively higher forms of animal life; until suddenly among the higher animals they come upon unmistakable indications of intelligent purpose; and then they say—Here mind appears, here for the first time we find evidence of mental life. Thus by following the principle of continuity they find themselves committed to a flagrant breach of the principle.

Search for Mind down the Scale

It is a sounder procedure to attempt to trace mind downwards in the scale, from man, in whom by common agreement we have the surest and clearest expressions of mind, endeavouring, by analysis of animal behaviour in the light of the analogy of human behaviour, to seize every indication of mental life, of purposive activity, as far down the scale as impartial observation warrants. When we follow this second and sounder procedure, we find good reason for inferring mental life in very lowly organisms and some facts which, supported as they are by the principle of continuity of evolution, indicate that even the simplest of animals (perhaps even some plants), the unicellular protozoa, are not entirely without the rudiments of mentality.

The evidence from palæontology, the study of fossil remains, which in respect of bodily evolution is perhaps the most cogent and convincing of all the lines of evidence, is almost wholly without parallel in the case of mental

evolution. Yet some such evidence of an indirect kind we have.

We have seen that the close correspondence or correlation between degrees of development of brains on the one hand and of mental functions on the other gives us some warrant for inferring the latter from the former. Now, though brains themselves are never preserved as fossils, skulls and other forms of skeletal support for the nervous system are so preserved, and serve to indicate the status of the nervous systems, and therefore also the mental status, of the animals of remote ages. It must suffice to say here that such scanty evidence of this nature as we have is fully in accordance with, and therefore gives general support to, the theory of mental evolution.

Two Descriptions of the Course of Mental Evolution

According as the student of mental evolution follows one or other of the two procedures defined in the preceding paragraph, according as he seeks to trace mind from below upwards or from above downwards, he is apt to arrive at one or other of two rival descriptions of its course. I propose to sketch in very general terms these two rival descriptions. The former may be called an attempt to describe the evolution of mind; for it is an attempt to describe the evolution of mind from something that is not mind. The other is a more modest attempt; it is content to assume that mind is something so distinct in its nature that we cannot properly (at least, in the present state of knowledge) pretend to trace its evolution out of anything other than mind. It is content to assume the reality of mind, or of mental activity, as something that we cannot hope to explain in terms of anything of a different nature; and aims merely at describing the evolutionary scale of mind from its simplest to its highest manifestations.

The Attempt to describe the Evolution of Mind

Herbert Spencer was the first to make a thoroughgoing

attempt to describe the evolution of mind. His attempt is an important part of his philosophy of evolution. He described at some length the successive stages by which the nervous system may properly be supposed to have become increasingly complex and increasingly integrated. And he described how at some unspecified stage of this process, a stage at which the interplay of nervous currents in the brain had become very complex, consciousness came into existence; the brain of some animal began suddenly to glow with a light that (up to that moment) never was on land or sea, an event of an absolutely novel kind in the history of the earth and perhaps of the universe. And he described how, from that stage onwards, consciousness became increasingly complex as the complexity and integration of the brain increased.

Lloyd Morgan—Emergent Evolution

More recently Dr. Lloyd Morgan has renewed the attempt, and sought to improve the description in a way that may avoid the too abrupt transition from the unconsciousness of the lower animals to the conscious activity of the higher animals, the appearance of an abrupt and tremendous discontinuity in the evolutionary process. He uses as the most general descriptive term for the assumed process one which forms the title of his recent Gifford lectures, namely, " Emergent Evolution ".[1]

Lloyd Morgan's description differs from Spencer's in two features of importance. First, it regards the emergence of mind or of consciousness as a special case of a more general class of phenomena, the phenomena of emergence of new qualities or realities in the course of the evolution of the universe, whereas in Spencer's scheme all evolution was essentially but the increasing complexity of processes of the same fundamental nature up to that moment when consciousness mysteriously " emerged ". Lloyd Morgan recognizes several such " emergences ", of which the chief are, first, " the emergence " of new chemical properties or qualities, when the synthesis or

[1] London, 1923.

integration of matter or energy or electrons or protyle reached a certain point of complexity; secondly, the emergence of the quality or property of life; and thirdly, the emergence of mind or consciousness.

The second difference is that in Lloyd Morgan's scheme this third emergence is represented as one of two stages widely separated in time. At some early stage of organic evolution there emerged a kind of inferior forerunner of mind, namely, mere sentience or crude sensation, a sort of consciousness that was conscious of nothing and could effect nothing, a mere epiphenomenon. With this passive sentience the lower animals (those still existing and those which during long ages constituted the whole of the animal world) are endowed. It was not until the nervous system was so far developed as to render possible the associative reproduction of sensations previously endured that consciousness in the proper sense emerged. Then for the first time the passive sentience was synthesized; and from the synthesis emerged consciousness proper, awareness of things, memory of the past, anticipation of the future, and effective striving in the present; then, and not till then, mechanistic causation began (in the brains of animals) to be modified by purposive striving.

By these modifications the Spencerian scheme is rendered, perhaps, more acceptable. The discontinuity involved in the emergence of consciousness is made to appear less abrupt, and " emergence " is made a more general feature of the evolutionary process. It may be said also that Lloyd Morgan frankly recognizes in primitive matter the potentialities of the later emergences. But such potentiality was at least implied in Spencer's account. Further, it may be said that Lloyd Morgan's account differs from Spencer's, in that he frankly admits the process of emergence to be creative. But this recognition of the creative nature of the emergent process is no part of the descriptive scheme. It belongs rather to the attempt to give some theoretical explanation of the course of events described. And Lloyd Morgan leaves us, as it seems to me, entirely in the dark as to this creative activity. He repudiates

in general terms the notion of activity as unscientific, as illegitimate in science. Yet, if the process is creative, we inevitably ask—What is the creative agency? Is it the evolving complex conjunctions of matter? Or is it some agent that plays upon the process of evolution from outside? To these questions no clear answers are given or implied in Lloyd Morgan's book. The reader is left with the impression that Lloyd Morgan remains a neo-Darwinian for whom natural selection is the all-sufficient principle for the explanation of evolution.[1]

The Description of the Evolution of Higher from Lower Forms of Mind

Those who attempt the lesser task, that of describing the evolution of higher from lower forms of mind, seek to trace the manifestations of mind from above downwards. They start out from man, in whom mind is most clearly manifested, and, attaching a certain weight to the principle of continuity, they are prepared to recognize purposive activity wherever its outward or objective marks can be observed. This procedure I regard as the more satisfactory, and the description to which it leads will now be briefly outlined.

We assert that we become acquainted with purposive activity in two distinct fashions. Each of us has immediate acquaintance with it as the experience of striving to attain some goal, as impulse, desire, effort, and volition; and sympathetic communion with other men enables us to feel sure that they have similar experiences, through which they also have such immediate acquaintance.

The Seven Marks of Purposive Striving

We observe that, when we ourselves and our fellow-men claim to enjoy such experiences, the movements of the bodily organisms commonly exhibit peculiarities that mark them as

[1] This statement perhaps requires modification in view of the fact that Lloyd Morgan is one of the co-authors of the important theory of organic selection.

different in kind from all the movements of inorganic things. These peculiarities we call the objective indications of mind, the objective marks of purposive striving. These marks are seven in number and may be briefly indicated as follows: (1) seeming spontaneity of movement; (2) persistence of the particular kind of movement (such as walking or swimming) in spite of change of circumstances and the cessation of the stimulation which may have initiated the movement; (3) variation of the movements in detail, while their general character is maintained; (4) the persistence of the movements until some change of a particular type is effected, upon which the train of movement ceases or gives place to another: an event which we know in ourselves to be accompanied by what we call " experience of satisfaction "; (5) the movements are such as to imply anticipation of, or preparation for, the kind of change of circumstance which they themselves tend to bring about: as when I lift my arm to ward off a coming blow, or a dog warily circles round an enemy with bared teeth and muscles tensed in preparation for combat; (6) improvement in effectiveness of the train of movement on repetition under similar circumstances: the objective mark of profiting or learning by experience; (7) the concentration of the whole organism upon the movements, a concentration indicated by the suppression or subordination to the dominant train of movement of all other bodily activities.[1]

We do not claim that the observation of any one of these seven marks justifies us in inferring the purposive character of bodily movement. But we claim that the presence of one or more justifies us in carefully looking for the others; and that, where all seven marks can be observed, there we may with some confidence infer that the movements are expressions of purposive striving.

When, equipped with these criteria, we attempt to trace mind downwards in the animal scale from man, we claim that all the higher animals, including all the birds and mammals,

[1] These objective marks of purpose and the argument founded upon them are set out in more detail in my *Outline of Psychology*, London, 1923.

exhibit unmistakably and abundantly trains of bodily movement that have all the seven marks of purpose; and we conclude that they are capable of mental activity. The case for mind is hardly less clear in some of the lower vertebrates and among some of the higher insects. Below this level we are less confident; for the lower we go in the scale the more difficult becomes both observation and interpretation, and the greater our ignorance of the observable facts. Yet among the worms and molluscs some species seem to exhibit forms of behaviour that are truly purposive, according to our seven criteria; as when the limpet returns again and again to his " home ", his spot upon the rock surface, after wandering freely in the neighbourhood; or as when the earth-worm tentatively explores the edges of a leaf upon the ground and then, seizing it by its acutest angle, draws it into its burrow.

Amœba

Even when we descend to the level of the simplest animals, the unicellular protozoa, similar evidence is not wholly lacking. The careful descriptions of several students, especially those of Dr. Herbert Jennings,[1] afford perhaps no instances in which all the seven marks of purpose are clearly exhibited in any one situation by one protozoan; but in the descriptions of successive observations we may discover all the seven marks of purpose; and it remains probable that, if we carefully seek for instances in which all the seven marks are combined, such instances may be found. Jennings himself has written: " So far as objective evidence goes, there is no difference of kind, but a complete continuity between the behaviour of lower and of higher organisms ". And he says that he is convinced " after long study of this organism, that if Amœba [one of the simplest of the protozoa] were a large animal, so as to come within everyday experience of human beings, its behaviour would at once call forth the attribution to it of states of pleasure and pain, of hunger, desire, and the like, on precisely the same basis as we attribute these things to a dog ".

[1] *Behaviour of the Lower Organisms.*

Consciousness

But, if this line of observation and inference inclines us to infer mind even in the lowest animals, are we to attribute to them "consciousness"? Would it not be wiser to content ourselves with postulating some such forerunner of mind as Lloyd Morgan's passive sentience? Does it not seem absurd to attribute consciousness to any one of the more lowly animals?

To these questions we reply as follows: the only ground for the attribution of mind to any animal (except in so far as the principle of continuity gives us some slight warrant for so doing) is its manifestation of behaviour bearing the objective marks of purpose. Nothing in the way of consistency and plausibility is added to our description of mental evolution by postulating the passive epiphenomenal sentience. To postulate such sentience as the forerunner of mind suffered by all the animal world for long ages before the evolution of true mental activity does but seem to soften and disguise the breach of continuity, by putting two smaller breaches in place of one large one. And it commits us to two assumptions for which we have no warrant in the facts of observation and which are incompatible with all that we know of the nature and function of mind.

So far as we can in any sense grasp the function of mind, it is essentially the function of guiding present action in relation to the course of events anticipated in the light of past experience. Mind is an active bridge or bond between the past and the future. The simplest conceivable mental function involves some awareness of the present, some memory of the past, and some anticipation of the future, however dim, vague, and formless such awareness, such memory, and such anticipation may be. And wherever we observe the objective marks of purposive striving, there we have ground for the attribution of mental activity in this full sense. To speak of consciousness where nothing is known, where there is no awareness of something, of some object, however vaguely and inadequately

conceived, is self-contradictory. Lloyd Morgan and other philosophers attempt to generate consciousness, or awareness of an object, or reference to an object (projicient reference is Lloyd Morgan's expression) by supposing that it may arise through the compounding of sensations which, uncompounded, have no rudiment of such function. This attempt is of very doubtful validity. The fundamental mental function is cognition or awareness of some object, prompting to striving in relation to it. This function is absolutely unique; we cannot hope to explain it in terms of any other. It is one of the ultimate realities; we have to accept it as a datum not capable of explanation. If two modes of sentience, each utterly devoid of objective reference or awareness, became compounded or synthesized, we have not the least warrant for supposing that the product will be, or will involve, awareness or the activity of knowing an object.

Continuity

The view of evolution to which we are thus led is not less, but rather more, consistent with the principle of continuity than is its rival. It postulates at most only one breach of continuity. For it regards life and mind as co-extensive; it assumes that, if there is discontinuity, it is between the organic and the inorganic realms. And all appearances indicate some absolute difference of kind between the two realms. Yet, if we attach high value to the principle of continuity, we can reconcile our view with it by assuming that even the processes of the inorganic realm are not truly and completely mindless; but that, rather, such objective marks of purposiveness as inorganic processes might show to an observer capable of intimately studying them, are hidden from us by the fact that we can observe these processes only *en masse*, and deal with them only in generalizations based on statistical averages. For we find that when we observe even human beings at long range and *en masse*, and describe their actions by the method of statistical averages, their actions take on the false appearance of mechanical determination and strict predictability. That is to say, we can avoid any breach

of the principle of continuity by adopting the monadic view of the whole world, organic and inorganic. And there are many philosophers who have regarded such a view of the world as presenting less and fewer difficulties than any other.[1]

Purposiveness and Awareness

These premises encourage us to look for the marks of purposiveness throughout the organic realm, and to infer mental activity wherever we discover those marks. And wherever we are led to infer the most rudimentary mental activity, whether in the inorganic realm, at the base of the organic realm, or at some higher level of the scale of organisms, we shall assume that it involves some dimmest vague awareness of something, and some striving, however nearly blind, towards a future goal.

We may attempt to understand the nature of such most rudimentary mental activity by reflecting upon occasional experiences of our own which consist in nothing more than a vague awareness and an almost blind impulse towards an end we do not clearly envisage. Thus in the still darkness of night in a wide solitude we may receive a sudden sense-impression that provokes an instinctive shrinking. The impression is so vague that we may be unable to say through which sense-organ it comes. It is a vaguest possible awareness of something there and a vaguest possible impulse of retreat.

Development of Rudimentary Mind

Such a rudiment of mental life being postulated, we may legitimately attempt to describe how in successive stages it may become developed and differentiated into the more discriminating perception that excites in the animal a more definitely directed impulsive or instinctive action. Such advance implies the development of mental structure in the species; a structure which is in the lower animals almost wholly innate

[1] For a recent persuasive statement of such a world-view I would refer the reader to a recently published book—*Philosophy of Character*—by Mr. Edgar Pierce (Harvard University Press, 1924).

in the species, that is to say, instinctive. The animals near the bottom of the scale of mind can distinguish, and react appropriately to, only a very few large classes of objects, most primitively perhaps only the noxious and the nutritious or desirable objects, reacting to the former with an instinctive movement of withdrawal, to the latter by a movement of approach or appetition.

From this level evolution advances by the further differentiation of the powers of discrimination; this is rendered possible only by the development of more differentiated sense-organs. But specialization of sense-organs alone will not constitute or bring about mental evolution. It must be accompanied by differentiation of the primary impulses and of the cognitive structure which enables the animal to become aware of objects of the several kinds from which the varied sensory stimulations proceed and to respond to each kind with the appropriate impulse. Thus, we may suppose, the class of noxious objects becomes differentiated for the evolving mind or organism into two or more kinds of noxious objects, each requiring a peculiar modification of the impulse to retreat. And the desirable class of objects becomes differentiated in a similar way into several such classes, each requiring a more specialized impulse of pursuit or appetition; for example, the sexual object and the nutritious object may be supposed to have become thus differentiated for the animal at an early stage by the differentiation of its sense-organs, its cognitive structure, and its impulse of pursuit.

Lloyd Morgan assumes that foresight of coming events could not be attained until the great distance-annihilating sense-organs had been developed. But, even if this were a well-based assumption (and it is not), it remains true that many of the lower organisms are sensitive to light and that some of the unicellular animals are equipped with what seems to be an eye-spot, or rudimentary eye. We may suppose then that such differentiation may have gone far while the sense-organs were still very simple in structure.

We may regard the lower vertebrates and some of the

lower insects as representing the degree of evolution that results from such differentiation of simple powers of perception and reaction. In the behaviour of each such species, we observe indications that it is "interested" only in certain great classes of objects, perhaps its food, its natural prey, its eggs, the males or females or the young of its own species, and certain natural enemies. To any object of any one of these classes it reacts in the appropriate instinctive fashion, remaining indifferent to all others. And, in so reacting, it may display but a rudiment of that adaptability to novel circumstances which is the fundamental mark of intelligence, namely, if it does not straightway attain its instinctive goal, it may vary the nature and direction of its movements from moment to moment, in a manner which makes the train of movement, within certain limits, a random process of trial and error.

Point of Divergence—Vertebrates and Insects

The stage of mental evolution described in the foregoing paragraph is that from which two possible courses lay open, by either of which a nicer adaptation to a greater variety of objects and conditions of the environment might be achieved. One of these lines was the greater specialization and differentiation of the instincts, the innate mental dispositions, the racial mental structures, which express themselves in instinctive behaviour. The other line was the increase of intelligence, or power of adaptation of instinctive reactions to the varying circumstances under which they are evoked. In the main the evolution of the higher insects followed the former line; that of the vertebrates followed the second course. This divergence gives some plausibility to Professor Bergson's sharp separation of instinct from intelligence. But M. Bergson has, as it seems to me, very seriously overstated the distinctness of the two functions and the two lines of evolution. Instinct and intelligence are not two distinct kinds of mental function; they are rather two abstractions that we make by considering mental process in two aspects in turn. All mental process is both instinctive and intelligent; it is instinctive in so far as it is

determined by innate mental structure; it is intelligent in so far as it involves adaptation to the particular circumstances of each occasion, circumstances not provided for in the racial mental structure.

The vertebrates, in developing along the line of intelligence, did not abandon their instincts. Nor did the insects, in acquiring more highly specialized instincts, cease to be capable of some degree of intelligent adaptation of instinctive behaviour.

The vertebrates in becoming birds and mammals underwent some further differentiation and specialization of instincts. Especially they acquired the parental instinct, the instinct that prompts them to shelter, feed, and protect their young. And this was a prime condition of the further evolution of intelligence. For the parental instinct rendered possible to the offspring of those species which had acquired it a period of youth, a period of irresponsibility during which, sheltered, fed, and protected by the parent or parents, they could develop their intelligence; that is to say, a period during which their instincts might slowly mature, while at the same time the young animal acquires a store of experience, builds up a complex mental structure corresponding to those varying features of its environment which are most closely connected with its instinctive pursuits. The young bird or mammal, during its period of youth, while its instincts are still maturing and not firmly set, learns, under the guidance of pleasure and pain, to make many discriminations not provided for by its innate or instinctive mental structure. It learns, for example, to distinguish more nicely between noxious and nutritious edible substances, and between those things which are dangerous and those which are harmless to it, even though threatening in appearance.

In proportion as intelligence develops in a species, the individual's own powers of discrimination are aided by traditional knowledge. In the gregarious species especially, though presumably in all species in which the young remain for a considerable period under parental care, tradition plays an important part in supplementing the efforts at discrimination

of each individual. These animal traditions are handed down, not of course verbally or with deliberate intention, but by such processes as the simple following of the parents by the young to places of shelter, to sources of food and drink, to appropriate habitats; and also largely by the process of sympathetic contagion of emotional reactions, the process which I have proposed to call " primitive passive sympathy ".

Thanks to this gradual accumulation of experience during youth, the bird or mammal begins its independent adult life with a large store of acquired knowledge, a mental structure differentiated far beyond the point to which the differentiation of the racial mental structure has attained. And, since the nature of this acquired knowledge or mental structure varies with each individual according to the particular circumstances under which its youth has been spent, the higher birds and mammals exhibit in their behaviour a much greater individuality and adaptability to a much wider range of circumstances than do the lower vertebrates and the insects.

The Apes

In the quadrumanous apes the mental evolution of the animals reaches its highest point. Their behaviour clearly reveals mental functions of a relatively high order, the evidence of which remains relatively slight and perhaps disputable in all the animals lower in the scale. Their behaviour implies that analytic intelligence which involves not only the recognition of one individual thing as distinct from all others, but also the apprehension of the relations between things, relations of time and place, of difference and similarity, of means to ends. Such apprehension is implied most clearly when the ape uses an instrument as means to a desired end; as when he seizes a stick and uses it to draw towards him a piece of food lying beyond his reach. And the range of memory and desire and their effective application are clearly shown when an ape, some hours after seeing attractive food buried in an inaccessible spot, goes at once to that spot on being liberated, and digs up the food.

The mental development of the individual ape is greatly promoted by the animal's possession of very effective organs of prehension and manipulation, its hand-like paws. Everywhere we observe some correlation between the possession of such organs and the degree of development of intelligence. For such organs greatly facilitate and promote the analytic perception of objects, the apprehension of relations between objects and parts of objects, and the use of objects as means to desired ends.

But in spite of the fact that the apes enjoy in a high degree the two great advantages we have noted, two great promoters of the development of intelligence, namely, parental care and the command of efficient prehensile organs, all the apes remain at a mental level vastly inferior to that attained by the most primitive men of whom we have any knowledge. This great superiority of the human mind to that of the highest of the animals seems to be due in the main to the evolution of a function that remains rudimentary in even the highest birds and mammals, namely the function of language.

Language

Language is essentially a social function, a means of communication. Primitively it serves merely to communicate, to spread, from one member of a social group to another, the primary instinctive and emotional reactions; as when the cry of fear or of anger, uttered by one member of the group, provokes in all members the same emotional behaviour or attitude. With advancing powers of discriminative perception, these few emotional signs became, we may suppose, differentiated into more special signs, each denoting some more special class of objects. Thus, the cry of fear, which at first was the undifferentiated sign of dangerous or threatening objects in general, may have become differentiated into several distinct cries, each denoting some special class of dangerous object requiring some specialized modification of the instinctive fear reaction. Thus emotional sounds would acquire more definite meaning; and these, combined with gestures such as pointing, would constitute

propositions; a member of a group perceiving an approaching tiger might utter a specialized form of the cry of fear and, accompanying it by pointing in the direction of the tiger, might virtually utter the proposition—" A tiger is over there ".

When the evolution of language had reached this stage, its use must have greatly promoted the advance of primitive man in the scale of intelligence. From the first appearance of the mammals in the later secondary period of the geological series, intelligence rather than bodily strength seems to have become the principal agent of survival, and therefore appears as the function in and through which the evolution process chiefly worked. Up to that time Nature seems to have experimented in the production of monsters formidable and able to survive in the struggle for existence by reason of their huge size and strength and, in many cases, their armour plates and other means of offence and defence.

With the appearance of the mammals the line of evolution changed. Bodily size and strength and resistance could not compete effectively with the increasing intelligence of smaller and relatively defenceless creatures; and the small-brained, relatively unintelligent reptilian monsters went down before the mammals.

And when, after further millions of years, language began to be the effective instrument of communication that it is, even in the simplest known forms of human speech, intelligence quickly gave to man the lordship over the rest of the animal world, raised him above their competition, and enabled him to use them for his own ends. For, in addition to serving as a means of immediate communication and call to action, speech performed for primitive man, as it still performs for every normal human child, several services of the highest value in promoting the development of intelligence.

Primitive emotional cries became differentiated into names for objects and classes of objects, and the use of names greatly facilitated the discrimination of such objects for each member of the social group. Further, the use of names must have greatly stimulated imagination and memory, by serving to

bring and keep before the mind the objects they denote in the absence of such objects; and this in turn must have promoted, not merely the play of phantasy, but also the art of planning action before the need for it arises, an art at first automatic and spontaneous, but later deliberate and intentional.

Judgment—Traditional Knowledge—Character

Again, when speech was so far developed as to permit the formation of propositions, it must have aided immensely in the development of analytic perception and analytic judgment, to take the place of those unanalysed practical judgments to which alone most of the animals are restricted.

And, most important of all, speech rendered possible the accumulation and enrichment of traditional knowledge to a degree only faintly foreshadowed in the lives of the highest and most sociable animals. To their participation through speech and hearing in this store of traditional knowledge men owe the chief part of their superiority to the animals. Without such participation men of average or even superior natural endowment would remain little more than animals, distinguishable from them only by the greater range of their memory and concrete imagination as revealed in their behaviour.

In spite of the immense development of intelligence that comes with the acquisition of language and participation through it in the stores of traditional knowledge, man's mental life continues to be founded upon instincts that are but little different from those of the higher mammals. The operations of those instincts are profoundly modified and deeply obscured by the play of man's intelligence, by his stores of acquired knowledge, and by his highly developed powers of discrimination.

Still more, perhaps, is the operation of the instincts modified and obscured in men of the higher type by that integration of the active or instinctive tendencies which we call character. Under the influence of the moral traditions of a well-organized society, the instinctive tendencies of the child become incorporated in the enduring and more complex dispositions that

we call sentiments, sentiments of love and hate, of respect, awe, and reverence. And these in turn become integrated in a single system within which, by the aid of memory, imagination, and reason, there take place constant reciprocal inhibitions and re-enforcements of tendencies which give to men's behaviour that consistency and constancy which entitle it to the name of conduct. And in the most favourable instances, this integration of active tendencies, involving sentiments of devotion to high and noble ends, becomes what we properly call moral character, the supreme product hitherto of the age-long process of mental evolution.

The Problem of the Agency at Work in Mental Evolution

In the foregoing rough descriptive sketch of the course of mental evolution, I have said little or nothing of the problem of agency, of the answer to the question—What forces, powers, agencies, factors, or processes have brought about this evolution?

This problem is closely involved with the general problem of biological evolution. The answer to the more special question must in some degree depend upon and be consistent with the answer to the more general question. The more general problem is discussed in various aspects in other essays of this volume and cannot be dealt with here. I must be content to make a few observations of a highly general nature.

It is now widely recognized that the strict neo-Darwinian theory of organic evolution is inadequate. This theory ignores mind or purposive activity as a possible agent of evolution, and strives to render an account of organic evolution, through the operation of selection alone, which shall consist with a purely mechanistic view of the world. It finds itself at the conclusion of its attempt with mind upon its hands as an enormous remainder or surd which cannot be intelligibly brought into the scheme and yet which cannot be ignored, save at the cost of absurdity of the whole scheme. Further, the neo-Darwinian

principles can account only for a pruning process by which the tree of life may have been clipped and shaped to its present form. They give no account of the genesis of those novelties of form and function, the successive appearance of which is the fundamental problem confronting every attempt to explain the fact and the course of evolution. Hence present-day biological science is much concerned with the problem of the origin of the variations or mutations with which and upon which natural selection must be supposed to work.

If it were permissible to assume the truth of the Lamarckian hypothesis, to assume that the modifications of structure and function which are achieved by the more or less intelligent efforts of individual organisms are transmitted in however slight a degree from parent to offspring, we should have in outline a complete theory of animal evolution, in which the Darwinian and the Lamarckian principles would be combined as they were by Darwin himself, by Spencer, and by most of the early Darwinians. In that theory of evolution mind or purposive striving would be assigned the honourable rôle of the essentially creative agency, the producer of variations, of novelties however slight, of creative steps however small.

But since at present the Lamarckian hypothesis is out of favour, for lack of any conclusive evidence in its support, and because of the difficulty of conceiving how the modifications acquired by the parent can be transmitted through the germ-plasm, we have to leave it unused.

But to reject, tentatively or wholly, the Lamarckian hypothesis is not to rule mind out of the account as a creative agency. Mind is the only creative agency of which we have any conception; and since organic evolution is a creative process, it would seem the part of wisdom to consider carefully all ways in which mind may have played a creative rôle, other than that assigned to it in the Lamarckian theory.

These considerations should lead us to attach much importance to those forms of selection in which mind does seem to play an active part, more especially sexual selection, organic selection, and various forms of social selection (involving

isolation and co-operation). Taken together these various forms of mental selection may be supposed to have played no inconsiderable rôle in the drama. But it remains difficult to see in them, as in natural selection itself, anything more than pruning agencies which may have shaped the course of evolution, but have not created new forms.

The only remaining possibility of assigning to mind the creative rôle which would seem to be proper to it is (so long as the Lamarckian hypothesis is untenable) to assume that the germ-plasm itself, or the reproductive cells, have enough of mental activity to produce the variations upon which all selective processes must be supposed to operate and without which they can produce no evolution.

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CHAPTER X

Physics and Chemistry

The Idea of Evolution as it applies to Matter

A definition of evolution might run as follows: the principle whereby groups of apparently independent entities (such as the species of plants and animals, chemical elements, &c.) are viewed as having been produced in the course of time from a very much smaller number of parent entities—hence a progressive and systematic development (the processes of which may be formulated as natural laws, whether physical or psychical) by which the known universe has come to be what it is. It may be said at once that very little of this view is strictly applicable to the inanimate world.

In the first place a physicist or chemist has to consider whether matter as we know it, in the form of some ninety different chemical elements, has in fact been produced from a very much smaller number in the past, and whether there has been a progressive development going on in the complexity of the material universe whereby it has come to be what it is. The more natural, if bald, question is: " Why are there some ninety different kinds of elements, and of what are they all made?" For elements, increase of complexity is indicated by increasing atomic mass rather than by any notable development in function, such as occurs with living organisms, where it connotes a definite ascent in the scale of the intelligence and the calibre of the organism.

However, it is very natural for the mind to refuse to believe

in the real independence of separate existences so nearly similar as are the chemical elements, and all the advances of physical science point to their close interrelationship, and to their being separate forms of essentially similar composition and structure. But the idea of progressive development with time from the simple to the complex is really wholly foreign to the subject. In point of fact, as present knowledge goes, although we now know cases of the more complex elements spontaneously changing into the simpler, it still remains entirely hypothetical whether, as has been so often supposed, the reverse takes place in nature at all. There is no valid reason to connect the simple with the past and the complex with the future. Nor is the question of the past and future cosmical history of the elements to be confused with the problem of artificial transmutation. To-day Nature is producing, in the radio-elements, transmutations which we are quite unable to accomplish, and to-morrow we may be producing transmutations which, like so many of our intelligent advances, inanimate Nature is wholly unable to effect.

In these circumstances it seems best to try to give to the student of the general subject so far as possible the actual present position of our knowledge bearing on the nature of the elements. Clearly we must first have a correct idea of what a chemical element is, and this was not arrived at till many confusions had been cleared away. The relationship of the elements to energy and electricity, as well as to one another, must be understood, or we shall be tempted to vague uninformed generalizations, like the ancients, without understanding the simplest details. The evidence that has been adduced for the evolution of matter in cosmical processes in the past, and the errors on which it was based, must be reviewed. In one case, however, we have more positive evidence of the existence of evolution or, as already indicated, devolution of the chemical elements than any that has yet been obtained for organisms, and that is in the case of the radioactive elements. This proves, for these special cases, the existence of the genetic relationships between the elements, which have been revealed

indirectly, but more broadly and generally by the Periodic Law and the definite family resemblances it discloses among the elements. The newer fields of physics and chemistry of the last quarter of a century bear most closely upon the subject, without as yet having completely solved the problem. We possess a clear mental picture of the internal structure of the elements and their atoms, and of the difference between one element or atom and another. We understand in general why artificial transmutation still eludes us. At the same time we have learnt to know of the existence of isotopes, and that the elements the chemist used to regard as homogeneous substances are in a large number, if not an actual majority, of cases mixtures of totally different substances. Clearly the time has now gone by for vague generalizations of the idea of evolution in the inanimate world.

The inanimate world as it is, apart from questions whether it was or will be any different, is, however, a sufficiently absorbing and intellectually satisfying study. Quite definitely and continuously, as knowledge advances and widens, interest in anthropomorphic speculation wanes, so that, to-day, just because positive knowledge was never so abundant, all attempts to forestall the march of knowledge by a too lively use of the imagination appear tawdry and unreal.

Substances and Qualities

The facile generalizations of the Greek school of philosophers of the sixth century B.C., as to the common origin of all things, are true rather to the minds that conceived them than to Nature. The Aristotelian " elements "—earth, air, fire, and water, to which later was added a " quintessence "—were all of the nature of essences or qualities rather than material substances. They found their way probably from the still more ancient East and represented the combination, two at a time, of a pair of properties, apprehended by touch, and their opposites—fire being dry and hot; earth, dry and cold; water, wet and cold; air, wet and hot; matter being a mere vehicle for the manifestation of more fundamental

qualities. They were the products of types of minds, even now too familiar, in revolt against the materialistic domination of things, and they were the cause of over 2000 years of mystical confusions, including the dark age of alchemy.

The distinction between material substances and qualities or properties was the *pons asinorum* of the physical sciences, and it is not fanciful to picture it in modern parlance as at bottom a distinction between matter and energy, the relation between which the theory of relativity canvasses in a new and interesting manner to-day. In its most rudimentary aspect, there would be an initial mental choice in any theory of matter between the idea of a single universal material with qualities infinitely variable according to its state of division and the relative positions or motions of its separate parts—the ancient view—and that of a number of separate fundamental kinds of matter, not mutually transformable, but each contributing a certain fixity of properties, capable of large but not complete modification by the factors of the relative position and motion (potential and kinetic energy) of the several components. The first view leads naturally enough to a belief in alchemy, while, on the second view, the question of transmutation becomes one of fact rather than deduction. The scientific attitude is necessarily pragmatic, that view which seems most to accord to the known facts being in the end preferred. On this test the ancient view was sterile and the modern fruitful in interpreting Nature and in the winning of new knowledge. It is open to the philosopher to retort that his view merely outstrips existing knowledge, and that the only conceivable end to increasing knowledge is the complete reduction of all types of matter to one simple type. But what the mind suggests is an altogether inadequate guide in the inanimate world.

One curious feature of these early times was the general contempt for the technical and utilitarian processes that underlay craftsmanship and industry. History records the names of none who made the early discoveries in chemistry and metallurgy which were to bring the world out of the Stone Age and inaugurate the succeeding eras of bronze and

iron. Yet the knowledge the ancients had of many metals, dyes, and medicines, glass, soap, starch, alcohol, and vinegar, despised in its day, remains unchanged to our own, and of how little of the ancient lore can as much be said!

It is difficult to understand the sway of the alchemical period over twelve centuries right up to the middle of the sixteenth—with its complete loss of the philosophical spirit and desire for truth as an end in itself, on the one hand, and, on the other, its degradation to the lowest forms of charlatanism and fraud—except by the political necessity for a continuous debasement of the currency which post-war sociology has demonstrated and explained. It was followed by an era of partial recovery, under the iatrochemists, Basil Valentine and Paracelsus, whose mercury, sulphur, and salt were on a par with the Aristotelian elements. While failing to see anything in the material world worth knowing for its own sake, these iatrochemists yet prized chemistry as the handmaid of medicine.

The definite revolt from these clouded views, and the full expression of the experimental as against the deductive method, came in the seventeenth century with Robert Boyle, " father of chemistry and uncle of the Earl of Cork ". We get with him the modern view of elements as the ultimate undecomposable constituents of matter in the purely experimental sense, so that by trial it might be found which were elementary and which compound, and, haply, when each element and its properties were known individually, some firm foundation for generalization might at length be reached.

But once more the cloud was to descend, and for a hundred years after Boyle the old battle between qualities and substance raged for the last time. The sulphur of the iatrochemists, as the principle of combustibility, later *terra pinguis* and finally *phlogiston*, was destined to bring the rival views to decisive test. Combustion, calcination, and even respiration —no mean generalization—were correctly regarded by the phlogistonists as analogous processes. As every schoolboy learns—before he has attained to the rank of thermochemical

equations—each is due to a *combination* of the substance burnt with the oxygen of the air, whereas the luckless phlogistonist envisaged it as a *decomposition* and due to an escape of the "element" phlogiston from the substance. The balance, in the hands, finally, of Lavoisier, was to overthrow this view, and the large gain in weight attending combustion is demonstrated on rough scales in every elementary chemistry course. But how modern the old views of phlogiston read, substituting for that strange term the modern one, "energy"! To "revive" a "calx" (reduce an oxide to a metal) or regenerate sulphur from sulphuric acid, the product of its combustion—in general, to reverse the process of combustion—it was recognized to be necessary to heat the material with a substance such as coal or oil, rich in phlogiston and highly inflammable. As we should say now—to reverse an exothermic reaction the energy evolved must be restored to the products of the reaction, irrespective altogether of the particular nature of the materials. Lavoisier established the law of the conservation of matter. However, what the phlogistonists were really worrying after, and indeed partially anticipated by more than a century, was the law of the conservation of energy.

The Chemical Elements and their Relationships

Three centuries have almost passed since the birth of Boyle, and the foundations have now been well and truly laid. In the present age we have witnessed a remarkable synthesis of knowledge and travelled far in our ideas as to the fundamental nature of things, though doubtless we have a long way to go before satisfying those who would measure inanimate Nature with a rule of life. So far from greater simplicity, the first result was extreme diversity. The desire to get to the root of the composition of substances perfected analytical chemistry. Elements confused in their compounds by the ancients, as iron and manganese, lead and molybdenum, nickel and copper, have been proved distinct, numerous classes of compounds have been broken up and the con-

stituent elements isolated, spectrum analysis added wholesale to the list, and the study of a single group—the rare-earth elements—all so alike that the ordinary methods would quite fail to separate them, resulted in fourteen being recognized. Radioactivity—of which more anon—contributed a small host, though only a few of them are *chemically* new, like radium. The net result is that we know eighty-seven different chemical elements and we know too that there are five more possible which one day may be found.

On the other hand, on its quantitative side, information of the composition of definite chemical compounds led directly to the establishment of Dalton's Atomic Theory. This does not vary continuously or capriciously from compound to compound, but can always be represented as due to some number, usually small, of one kind of atom of a certain constant weight combining with another number of another kind of atom of different constant weight. Every uncertainty was in due course eliminated, and it became possible to determine to a very high degree of precision the relative atomic weights of all the elements, from the proportions in which they combine to form compounds, in conjunction with physical methods of determining the weight of the compound molecule.

Then, as Boyle foresaw, true knowledge of the nature of elements in general began to emerge from the mass of detail. The Periodic Law, connecting the chemical character of the element with the atomic weight, brought a kind of order into the diversity, but itself proved a veritable cryptogram. It was first arrived at in 1864, in a necessarily very imperfect form, since only some sixty of the elements were known, by Newlands, who called it the Law of Octaves from the analogy to the notes of a musical scale. It is only very recently that definite evidence has been obtained that the present form of the Law is final, and that no unexpected chemically new elements are likely to be discovered. The Periodic Table of the elements is shown in fig. 1. The law may be described thus:

Arranged in increasing order of atomic weight, the ele-

Periodic Table of the Chemical Elements

	Group O	Group I	Group II	Group III	Group IV	Group V	Group VI	Group VII	Group VIII		
1 Hydrogen 1 008	2 Helium He 3 99	3 Lithium Li. 6 94	4 Beryllium Be. 9·1	5 Boron B. 11·0	6 Carbon C. 12·00	7 Nitrogen N. 14·01	8 Oxygen O. 16·00	9 Fluorine F 19·0			
	10 Neon Ne 20·2	11 Sodium Na. 23·00	12 Magnesium Mg. 24·32	13 Aluminium Al. 27 1	14 Silicon Si. 28·3	15 Phosphorus P 31·04	16 Sulphur S. 32 07	17 Chlorine Cl. 35·46			
A	18 Argon A. 39 88	19 Potassium K 39·10	20 Calcium Ca. 40·07	21 Scandium Sc. 44·1	22 Titanium Ti 48·1	23 Vanadium V 51·0	24 Chromium Cr 52·0	25 Manganese Mn. 54 93	26 Iron Fe. 55·84	27 Cobalt Co. 58·97	28 Nickel Ni. 58·68
B		29 Copper Cu. 63 57	30 Zinc Zn 65 37	31 Gallium Ga. 69·9	32 Germanium Ge 72·5	33 Arsenic As 74 96	34 Selenium Se 79·2	35 Bromine Br. 79·92			
A	36 Krypton Kr. 82 92	37 Rubidium Rb. 85·45	38 Strontium Sr 87·63	39 Yttrium Yt 89 0	40 Zirconium Zr. 90·6	41 Niobium Nb 93·5	42 Molybdenum Mo 96·0	43 ———	44 Ruthenium Ru 101 7	45 Rhodium Rh 102 9	46 Palladium Pd. 106·7
B		47 Silver Ag. 107·88	48 Cadmium Cd. 112 40	49 Indium In 114·8	50 Tin Sn. 119·0	51 Antimony Sb. 120·2	52 Tellurium Te. 127 5	53 Iodine I 126·92			
A	54 Xenon Xe 130·2	55 Caesium Cs. 132 81	56 Barium Ba. 137 37	57 Lanthanum La. 139 0	58 Cerium Ce. 140·25	59 Praseodymium Pr. 140·6	60 Neodymium Nd. 144·3	61 ———	62 Samarium Sa. 150·4		
		63 Europium Eu 152 0	64 Gadolinium Gd. 157 3		65 Terbium Tb 159·2	66 Dysprosium Dy. 162 5		67 Holmium 163·5	68 Erbium Er. 167 7		
		69 Thulium Tm 168 5	70 Ytterbium Yb. 172·0	71 Lutecium Lu 174·0	72 Hafnium	73 Tantalum Ta. 181·5	74 Tungsten W 184 0	75 ———	76 Osmium Os 190 9	77 Iridium Ir. 193·1	78 Platinum Pt. 195·2
B		79 Gold Au 197 2	80 Mercury Hg 200 6	81 Thallium Tl. 204·0	82 Lead Pb. 207 20	83 Bismuth Bi 208·0	84 Polonium (210)	85 ———			
A	86 Radium Emanation (222)	87 ———	88 Radium Ra. 226 0	89 Actinium	90 Thorium Th. 232·12	91 Uranium X_2 (Brevium)	92 Uranium U. 238 18				

Only spaces marked ——— are vacant places. The figures above the name of the element are the atomic numbers, and those below the atomic weights

Fig. 1

ments, as they succeed each other, differ from their neighbours in a marked and regular manner, the normal valency of the element first increasing by one to four and decreasing to zero again. After a certain definite sequence, similar elements appear and the sequence repeats itself. Thus the five nonvalent or inert gases of the atmosphere, helium, neon, argon, krypton, and xenon, are the 2nd, 10th, 18th, 36th, and 54th; the four monovalent halogens, fluorine, chlorine, bromine, and iodine, are the 9th, 17th, 35th, and 53rd; the five monovalent alkali metals, lithium, sodium, potassium, rubidium, and cæsium, are the 3rd, 11th, 19th, 37th, and 55th. At first the number of elements in the period, before the sequence recommences, is eight, later eighteen; at the 57th element, lanthanum, thirteen more very similar elements—the rare-earths—are inserted and then the former periodicity is resumed up to the last and 92nd element in the table, uranium, of atomic weight 238 (oxygen = 16). There are several obvious misfits. Tellurium of atomic weight 127·5 precedes instead of follows iodine of atomic weight 126·9, and similarly cobalt precedes nickel and argon potassium, though from the atomic weights the reverse should be true. These exceptions will be again reverted to.

Prout's Hypothesis

A hypothesis in itself of no great originality or importance was put forward in 1815, shortly after the enunciation of the atomic theory by Dalton, by an Edinburgh doctor, named Prout, but much of the subsequent history right up to the present day is conveniently discussed with reference to it. It was nothing else than the original Greek view of the common origin of things, made explicit by taking hydrogen as the fundamental substance or protyle, and regarding all the other elements as built up out of it. On this view the atomic weights of the other elements should be whole numbers on the basis of that of hydrogen as unity. As the determinations became more and more exact, it was found that Prout's hypothesis could not be correct, but that there was some integral

relation between atomic weights was also evident. It may be said at once that no chemist could possibly regard the elements as compounds of hydrogen in the same sense as water is a compound of hydrogen and oxygen. As time went on, it became clear that if the chemical elements were built up out of simpler materials, the nature of the union must be much more intimate than in any chemical compounds. For though the changes attending chemical combination are often striking, and the properties of the compound bear little, if any, relation to those of its constituents, yet evidence of the continued existence therein of the original elements is never very far to seek. One does not, for example, when an atom of carbon, 12, unites with an atom of oxygen, 16, to give carbon monoxide, 28, get from the latter on decomposition, silicon, 28, or nitrogen, 14, or lithium, 7, but only carbon and oxygen again. In the form, then, that there existed a much closer union than chemical combination in which all trace of the original atoms was lost and new atoms of different elements resulted, some such hypothesis as that of Prout could always be legitimately canvassed.

In the first place, the fundamental ratio of the atomic weights of oxygen and hydrogen is not exactly 16 to 1, but 15·88 to 1, or 16 to 1·0075. However, if oxygen as 16 instead of hydrogen as unity is made the basis of atomic weights, a very large proportion of them become nearly integral, and, if for no other reason than convenience in memorizing these constants, the basis $O = 16$ is now always adopted.

On this basis many of the atomic weights—such as carbon 12, fluorine 19, sodium 23—are exact integers, and a considerable proportion are so nearly integral that the difference may in some cases be due to experimental error. True there are many with fractional atomic weights, notably such elements as chlorine 35·46, magnesium 24·32, neon 20·2. But a statistical investigation established beyond reasonable doubt that the number of integers was too great to be due to chance, and that some reason must exist for the preference for whole numbers which so many of the atomic weights display. The

solution of this conundrum also belongs to our own times, and may for the present be deferred.

The Spectra of the Sun and Stars

We have seen that the question whether or no the elements are really fundamental kinds of matter, or whether they are built up out of simpler forms, is in the first instance one of experimental fact. But the conditions realizable in a laboratory experiment are very restricted compared with those common enough in cosmical processes in Nature, especially as regards the attainable limits of temperature and pressure. The stability and permanence of chemical elements may be the result of their having already been subjected to pressures and temperatures beyond those we can command, their mere existence, on the principle of the survival of the fittest, connoting a degree of conservatism that defies our efforts to change them. The spectroscopic analysis of the sun and stars reveals in the main the same elements as those we know upon the earth. True, helium was discovered first, from its prominent line, D_3, in the spectrum of the sun's chromosphere in 1868 and not upon the earth till 1895. Also, from lines not yet identified with the spectra of known elements, the existence of other "stellar" elements has been inferred—coronium in the solar corona, asterium in some stars, and nebulium in nebulæ. The same is true of a green line in the aurora spectrum, and indeed observed two nights out of three in the spectrum of the light of the night sky. The Periodic Table in its present form seems definitely to rule out the possibility of such new elements—though it accommodated helium readily enough—and there is a growing disposition to regard these lines as emanating from types of spectra not yet reproduced in the laboratory rather than from new elements.[1]

[1] Vegard's recent identification of the green auroral line with one in the spectrum of frozen nitrogen bombarded by cathode rays has been controverted by M'Lennan and Shrum on the ground that the lines in question are not exactly coincident. Vegard, however, maintains his original conclusions.

The spectrum of a star affords, however, evidence of its temperature, and, as Norman Lockyer put it in 1873, " The hotter the star, the more simple is its spectrum ". A pioneer in stellar spectroscopy, he brought forward much evidence for the view that stars originate out of nebulæ by condensation accompanied by rising temperature, attain a maximum temperature, and then cool. During the initial period he imagined the original elements, constituting the meteors out of which the nebula is composed, becoming, with increasing temperature, transmuted into simpler forms. The ordinary lines of the spectra give place to the so-called " enhanced " lines, which are the lines that appear in the spectra produced by the " spark " of a Leyden jar discharge and are not usually present in the " arc " or " flame " spectra. At the temperature maximum the spectra show little besides hydrogen and helium, the two simplest elements, but in the cooling stage the metals and lastly carbon reappear. On the strength of this he advanced a wide scheme of *Inorganic Evolution* (Macmillan & Co., 1900). One has only to re-read this work to understand how much of the reasoning has been invalidated, so far as it bears upon any actual transmutation occurring in cosmical evolution. In fact, as his biographer has said,[1] modern thought has definitely departed from this hypothesis. Changes of spectra, then thought to indicate a veritable transmutation of a complex into a simple element and to be due to high temperature, are now known to be entirely electrical in character. The " enhanced " lines are caused by a higher degree of ionization of the atom, i.e. two or more of its superficial electrons have been detached from the atom instead of only one as in the ordinary " arc " spectra. The phenomenon of elements giving different types of spectra under different conditions of excitation must now be regarded as the spectroscopic equivalent of changes exactly analogous to changes of valency in chemical reactions and does not indicate more deep-seated alterations of the atoms themselves.

[1] *Proc. Roy. Soc.*, 1923, **A**, **104**, vi.

In the second place the discoveries in radioactivity have enabled us to watch on earth the course of veritable transmutations of one element into others. The general demonstration that colossal changes of energy are involved in such transmutations, which proceed at rates totally uninfluenced by temperature or any other known factor, cuts away the basis from the facile cosmogonical speculations that before appeared reasonable enough. To Lockyer high stellar temperature was the obvious cause of the supposed transmutation of the complex elements into the simple, whereas now it would be more plausible to regard it as an effect, provided transmutation really occurred, the cause being unknown and probably not due to temperature at all. Be that as it may, " the hotter the star, the simpler its spectrum " appears to be a dictum that the great advances in the subject have left substantially true. It remains one of the few pieces of positive evidence in favour of transmutation occurring in processes of cosmical evolution. But modern workers have not yet found it necessary. For example, the most recent results of Eddington, which lead him, among other very startling conclusions, to assign an average molecular weight to the constituents of all stars alike of only 2·1 (H = 1), find their explanation equally well whether ionization or transmutation is assumed, because the average molecular weight in question refers to a mixture of both ionized atoms and electrons. But in this case the ionization assumed is of a far more drastic character than is observed in chemical changes.

The Atomic Theory of Electricity

" Electron " is Greek for amber, and the fact that amber when rubbed with cloth attracts light bodies to it seems to have been the sole knowledge of electricity possessed by the ancients—fortunately, perhaps, or what further inextricable confusions between energy and matter might not have resulted! For electricity, in modern thought, occupies an intermediate category, combining some of the most characteristic features of both protagonists. The view that elec-

tricity like matter possessed a discrete structure and existed in the form of separate units or atoms, all of equal indivisible amount, though it is implied in Faraday's well-known laws of electrolysis, reached a rapid culmination towards the end of last century with the isolation of the negative electron as the "cathode-ray" in experiments on the electric discharge *in vacuo*. No similar electron of positive electricity has been isolated, and none is believed to exist. The negative electron is the real atom of electricity, and, as for positive electricity, it is matter. That is to say, the normal electrically neutral condition of matter is due to its combination with a sufficient number of negative electrons to neutralize its inherent positive charge. The terms positive and negative are thus unfortunately inverted, as it happens, but it would be idle now to attempt to rectify the nomenclature.

Once apprehended and characterized, the electron was found to be ubiquitous, capable of separation from any kind of matter, which thereby acquires an equivalent positive charge, as well as the active cause of the phenomena of radiation, electromagnetism, chemical affinity, and most of the common physical properties of matter. Some curious misconceptions have gained currency under the name of the electrical theory of matter. It is better to give a brief elementary review of the fundamentals as they appear to-day and to leave the reader free to form his own generalizations.

Considered at rest, the electron is a minute charge of negative electricity—$4{\cdot}6 \times 10^{-10}$ electrostatic units—usually regarded, for lack of any evidence as to its real shape, as the equivalent of a sphere of radius 10^{-13} cm., or $\frac{1}{100000}$ of the average atomic radius, and therefore much the most minute as it is the lightest individual particle known to science.

Its outstanding and most important characteristic (of which, by the way, the general reader is rarely clearly informed) is its power to repel other electrons and to attract positive ions (i.e. atoms deprived of one or more of their constituent electrons) with forces quite beyond our power to conceive, i.e. if we deal with the electrons and atoms in

any chemically detectable quantity of matter. The most powerful actions with which we are acquainted in chemistry or electromagnetism are due to a small unbalanced resultant of these primary forces, between the atoms of electricity or the atoms of matter operating upon themselves (repulsive), and between the atoms of electricity and of matter acting on each other (attractive). In other words, neither kind can exist free in any numbers—the vast majority of both kinds are already in combination. Common electrostatic and chemical actions are due either to minute disparities between the number of each kind, or to new orientations between them. It would be difficult to picture a world of one kind without the other. It would dissipate itself to the confines of space, and this reflection may possibly account for the fact that we always get them in practically equivalent quantities in real life.

The hydrogen atom is the simplest example. It is compounded of the monovalent positive ion, H^+ (positive charge $4{\cdot}6 \times 10^{-10}$ e.s.u.), around which at a distance of 10^{-8} cm. an electron of equal and opposite charge revolves. Were it possible to isolate the two components, even for an amount of hydrogen insufficient to show its spectrum in a vacuum, no vessel, were it built as strongly as a modern wire-wound gun, could contain either of the two parts separate. It would be burst by the mutual repulsion of the separate unneutralized charges.

In motion, the electron retains its electrostatic character as a charge, but takes on new electromagnetic characters, as a current of electricity, surrounded in space by a field of energy capable of influencing the motion of other moving charges. If its motion is changed, either accelerated or retarded, this field changes in strength appropriately. If the change is rhythmic, as in the case of the in-and-out surging of electrons in a wireless transmitting aerial, or of the motion of the electrons inside the atom, the rhythmic change in the magnitude of the field, transmitted through space with the speed of light, constitutes radiation—wireless

waves, heat and light rays, X-rays, γ-rays, in order of the frequency or rapidity of the periodic change.

This phenomenon, constituting as it does a veritable transmission of energy through space, cannot occur unless this energy is supplied. Thus to accelerate an electron from rest requires the expenditure of work upon it, and, if it is stopped, an equal amount of work must be given up by it. It resists the effort to stop and start it for all the world like a material particle. That is, it has inertia and therefore mass.

True, in our dealings on the earth we look upon weight as a more convenient measure of matter, but inertia is its primary measure, being completely independent of gravitation and the proximity of a world. So arises the question whether there are two kinds of mass, one due to the well-known electromagnetic reactions which attend the starting and stopping of a current of electricity, and another of unknown origin possessed by matter. Or, can all mass be regarded as of electromagnetic origin? This cannot be regarded as settled, but it is probable that the mass of the electron itself is wholly electromagnetic, and it is at least possible that all mass is of the same character.

The Electrical Theory of Matter

The question therefore arises as to the precise difference between an electron and a positive ion, say H^+. The answer is chiefly in the magnitude of the mass. By very beautiful physical methods Sir Joseph Thomson and his successors have proved that the mass of the electron is $\frac{1}{1825}$ of that of the hydrogen atom. In other words the atomic mass of electricity is 0·00055 (H = 1), though we can scarcely speak of its atomic weight, seeing that it exhibits so spirited a contrast to the law of gravitation.

These methods have now come into universal use for the determination of the atomic mass of any individual particle bearing an electric charge—not only the electron on which it was first used, but also the positive ions in the electric discharge

through gases and the radiant α- and β-particles expelled by the radioelements as well as those these in turn expel from other atoms. They depend upon the fact that the path of a moving electron or charged particle is curved by the action both of an electrostatic and of an electromagnetic field, the curvature being, for the first, dependent on the kinetic energy, and, for the second, dependent on the momentum of the moving particle. Strictly, it is not the mass but the ratio of the charge to the mass that is found by this method, but as electricity is atomic, and the only question that arises is as to the number of atomic charges carried by the particle, the difficulty is surmountable. It is in fact the same as that which confronted the early efforts of chemists to determine the atomic weights from the chemical equivalents, which involved a knowledge of the valency of the atom, and that is, on the modern view, the number of atomic charges of electricity that it carries when combined. At this stage, the great difference between the old chemical and the new physical methods of determining atomic weight may be emphasized. The old gave necessarily an average atomic weight for all the atoms of the same chemical character, whereas the new is capable of distinguishing between atoms of different mass and identical chemical character (isotopes).

If we decide to adopt the view that all mass is electromagnetic in origin, the question arises how the 2000-fold greater mass of the positive hydrogen ion as compared with the negative electron is to be explained. The electromagnetic inertia of a charged sphere varies inversely as its diameter, so, since the charges are equal and opposite, the diameter of the hydrogen ion must be only $\frac{1}{2000}$ of that of the electron, or only 10^{-16} cm. The modern nuclear theory of atomic structure confirms this view but on quite direct independent evidence, as we shall come to see. It raises certain difficulties, apparent perhaps rather than real. For the hydrogen ion is very well known both in the phenomena of "positive rays" of the vacuum tube, and in the electrolysis of liquids. Indeed it is the common constituent

that confers " acidity " on all acids, and, apart from theoretical reasoning, there has been nothing hitherto to suggest that it is as much smaller than the electron as the electron is than the atom. Perhaps for this reason the practice has grown up of distinguishing by a special name, " proton ", the hypothetical hydrogen ion of diameter 10^{-16} cm. and unit mass in the more recent developments of Prout's hypothesis, from the known hydrogen ion of electrolysis.

Even if we accept these ideas it would be a mistake to suppose that matter had been resolved into electricity. There are still two fundamental units in atomic structure, the electron and the + ion, and the resolution has been rather into electricity and matter than into − and + electricity. For + electricity on this view has every one of the ordinary features of matter in addition to its electric charge, and even its further resolution into a collection of protons and electrons cannot really be said to constitute more than a verbal preference for calling matter positive electricity.

Radioactivity

The range of chemistry and physics was definitely increased in 1896, when, a year after Röntgen's discovery of the X-rays, Becquerel discovered the natural radioactivity of the element uranium. This discovery was rapidly followed by the remarkable investigations of M. and Mme Curie on radium and other new radioelements, and the subsequent development of this subject has thrown a new light upon the nature of all the elements. It is not too much to claim that now, scarcely more than a quarter of a century from the initial observation, we possess an insight into the new field superior in definiteness and completeness to that possessed in any other experimental subject. Radioactivity is pre-eminently an exact science, because it deals with fundamental material processes entirely outside our power to influence in their course in the slightest degree, and it would appear to be about as feasible to alter the result of adding two and two as to alter the course of radioactive phenomena. This feature of inevitability and

determinateness, so foreign to all the common physical and chemical processes with which we have been so long familiar, facilitated the initial survey of the subject, but now appears as a formidable barrier to further advance. It cannot be too strongly insisted that radioactivity is a very special phenomenon, uniquely concerning two only of the ordinary chemical elements, uranium and thorium, the two heaviest elements at the end of the Periodic Table, though it is possible that in potassium and rubidium something more or less analogous may be taking place. Uranium and thorium are undergoing a slow spontaneous process of devolution into lead, helium, and electrons, through a long series of much more rapidly changing, and much more intensely radioactive intermediate elements—radium, actinium, ionium, radio-lead, and polonium from uranium, and mesothorium and radiothorium from thorium, to mention a few of the more commonly known. The changes involved, though excessively complicated in that a long series of successive transformations occurs in the case of both elements, in all over forty being now recognized, are nevertheless of the simplest type individually. All are what the chemist would term "first-order" or "monomolecular" reactions, the rate of change of any one radioelement at any instant being simply proportional to the quantity of changing substance existing at that instant. This is the theoretical law for a change self-contained within the individual atoms or molecules of a homogeneous substance. For a combination, or for any reaction involving more than one substance, the rate of change is connected with the quantity of the changing substances in a more complex fashion.

Though the underlying cause is still quite unknown, the actual process of atomic disintegration which causes radioactivity is clear in every detail, and may be stated thus. Out of any number of atoms, N, of a radioactive element, some fraction, λN, where λ is a constant, known as the radioactive constant, disintegrate or explode in the unit of time, expelling rays and changing into the next product of the disintegration series. λ is a *real* constant, different for and characteristic of

each of the forty changing radioelements, but completely unaffected by every known circumstance. It is particularly significant that it does not in the least depend upon the past period of time the radioactive substance has been in existence, and it is easy to show by experiment that it has the same value for a collection of new-born atoms, freshly formed from their parent substance, as for an old lot, for example, the small residuum surviving a period of existence many times the average. The reciprocal of the radioactive constant λ, i.e. $1/\lambda$, expresses the average period of life of the substance in the time units to which it refers. It must be emphasized that for the individual atom the atomic explosion is a sudden process. For the mass of the radioactive substance the disintegration is gradual, a new set of atoms becoming unstable and breaking up in each successive period of time.

One thus has to regard radioactivity as a property superimposed on the ordinary physical and chemical character. Only a certain, usually minute, fraction of the atoms are actually disintegrating in any instant. As for the rest, they are not even preparing to disintegrate, as otherwise the period of average life would not be independent of the age. Of the N atoms λN explode per second, but which ones explode is pure chance. The lot is just as likely to fall for one as for another, and the life of any individual atom is thus even more uncertain than that of a man.

In these atomic explosions the atom breaks into two parts. The lighter part is expelled as a ray or radiant particle. Two kinds of these are known, considered more nearly in the next section, the α- and the β-particles. The rest of the atom, constituting by far the greater part, appears as the product of the change, and in due course explodes again and again. In each successive change, from each atom one such new atom is formed and one radiant particle, either an α- or a β-particle.

Let us take as an example the first changes of radium, this element itself being the fifth successive product in the disintegration of uranium. Every second thirteen in a billion of the radium atoms in existence expel α-particles and turn

into the atoms of a new radioelement, radon or the radium emanation. This is a gas, capable of being condensed at the low temperature of liquid air, and chemically quite inert or nonvalent. For radon, two per second per million of the atoms in existence are chosen and expel α-particles again, turning into a solid substance, also radioactive, known as radium A. Through radium B up to the final product radium G, which is lead, the changes run, at each change either an α- or a β-particle being expelled per atom disintegrating.

For the primary radioelements, uranium and thorium, the periods of average life are measured in thousands of millions of years, which is the equivalent of saying that each year one part in seven or eighteen thousand million suffers disintegration. The sole reason why such almost infinitely slow changes give any experimental effect capable of detection is that the energy evolved in these changes is of a hitherto unheard of magnitude. Radium, for example, the period of average life of which is 2400 years, gives out every forty-five minutes as much heat as would raise its own weight of water from freezing- to boiling-point, and one has only to total up this emission for the period of its average life to obtain a quantity of energy of the order of a million times as great as that evolved in the most energetic chemical reactions known. Nor is there the least uncertainty about this, because of the short span of human life, for if one takes the shorter-lived substance, radon, of period of average life 5·3 days, and performs the same calculation, one gets a similar result, and this applies to a change one can follow from start to finish in the course of a month. For every 1 gm. of radium, there would be 0·6 cubic millimetres of radon present in equilibrium conditions.[1] Yet this infinitesimal quantity of gas can be shown

[1] *Note on Radioactive Equilibrium.*—The product of a radioactive change necessarily accumulates with time to a fixed equilibrium proportion relative to that of the parent, given by the condition that the loss through the further change of the product exactly balances the gain through its production by the parent. This yields the simple law that in any disintegration series the successive products accumulate to definite equilibrium ratios, which are proportional to their average life periods. In the present instance, 1 gm. of radium bears the same proportion to the weight of

by experiment to be emitting energy at the rate of something like 100 calories per hour. If one could obtain a single cubic centimetre of it, for which nearly 2 kgm. of pure radium would be necessary, no vessel would hold it as it would give out as much heat as a 4-ampere arc lamp and melt the walls.

The α-, β-, and γ-Rays

The mathematical evidence shows that the changes taking place in radioactive matter are of the nature of self-contained single-system changes. The physical and chemical evidence is equally satisfactory in proving that they consist of veritable transmutations. Two types of change are known, differing only in that it may be either an α- or a β-ray that is expelled by the disintegrating atom, and first we must consider the nature of these rays.

α-Rays.—The α-rays are the least penetrating but by far the most important as they are also the most novel of the rays from the radioactive substances, and they possess well over 90 per cent of the total energy evolved in radioactive changes. We owe most of our very precise knowledge of them to Sir Ernest Rutherford, who has made them a subject of exhaustive study. From the occurrence of helium in uranium and thorium minerals, as discovered in 1895 by Sir William Ramsay, after the general nature of radioactivity had been elucidated it was thought likely that this helium was the product of radioactive changes and that its production was connected with the α-radiation. The continuous production of helium from radium, and later from actinum, polonium, and other of the radioelements giving α-rays, was established by actual spectroscopic examination in 1904, and this indeed constituted the first direct proof by the older methods that these changes are really transmutational. Rutherford found that the tra-

0·6 cu. mm. of radon, as 2400 years to 5·3 days, and, indeed, it was from this relation and the known period of radon that the life of radium was first deduced. Again, from the latter figure and the experimental datum, that in radioactive minerals there is always one part of radium per three million of uranium, one arrives easily at the approximate period of the latter, viz. 2400 × 3,000,000 = 7,200,000,000 years.

jectory of the α-rays could be deviated by very powerful electrostatic and electromagnetic fields, and so proved them to consist of charged particles moving at high velocities. The application of this method to the determination of the atomic weight of the radiant α-particle proved that it consists of a doubly positively-charged helium atom, He^{++}, that is to say, of a neutral atom of helium that has lost two electrons in the atomic explosion in which it is generated.

The velocity with which the α-particle is ejected by the disintegrating atom is between one-thirteenth and one-twentieth of that of light, i.e. from 14,000 to 9000 miles a second, and owing to this high velocity it possesses, like the radiant electron or cathode-ray, a limited power of penetrating all kinds of matter, before its energy is spent. This energy gives the α-particles the power to cause substances like zincblende, upon which they impinge, to shine brightly. Indeed, by this means, a single α-particle can be detected as a flash or "scintillation" and so the actual number expelled in the unit time from radium has been counted. Though the kinetic energy is so high, the penetrating power is small, amounting to only from two to three inches of ordinary air, yet sufficing to carry the α-particle through a *very* thin film of mica or glass. One of the most beautiful experiments ever performed established the definite identity of the α-particle with helium. A glass capillary tube was drawn so thin in the wall that the α-particles could penetrate them. It was first filled with helium and found completely gas-tight. Then it was filled with a few tenths of a cubic millimetre of radon, which gives α-rays in each of four successive changes, and powerful α-rays could be shown to be escaping from the tube by holding near it a zinc sulphide screen. The tube was then surrounded by another, exhausted of all gas, and after a few days the exhausted space was found to contain enough helium to give its spectrum, proving that the α-particles which are shot through the tube are helium atoms, though ordinary helium gas could not pass.

This penetration of the atoms of matter by the radiant

helium atom raises questions of the highest philosophical importance, the pursuit of which has proved as fertile as the disquisitions of the schoolmen, upon whether two pieces of matter could occupy the same place at the same time, proved barren.

Sir William Bragg established that, in all the millions of encounters with the atoms of matter in its path, the α-particle barely deviates from a straight line, that is to say, it ploughs through them almost *as though they were not there*. Then it was found that in *some very minute proportion* of the encounters the α-particle is sharply turned, it may be even to return the way it came. Just so a rogue sun, let loose in the universe, might plough through many solar systems as though they were not there, hardly affected by small fry in its path like planets, and only once in a while passing close enough to the central sun of a solar system to be turned back like a comet at perihelion. The absolute aptness of this simile is made apparent in many of the beautiful cloud photographs by means of which C. T. R. Wilson and his successors have succeeded in photographing and later in cinematographing the tracks of α-particles through gases.

One of Wilson's photographs is shown in fig. 2. The α-rays proceed from a needle point not shown in the picture, carrying an infinitesimal quantity of a radium salt. They pass through moist air which is suddenly chilled by expansion at the instant the photograph is taken. The cloud of water-drops so formed condenses preferentially upon the ions produced in the tracks of the rays, thus revealing them in every detail. One can see thus the normal almost dead-straight track, the occasional sharp turn, and in certain cases one can even see the atom struck recoiling as a spur at the fork of the track! It is upon these phenomena that the modern theory of atomic structure is based. They have shown that at the centre of the atom is an exceedingly minute nucleus, in which substantially all the mass is concentrated, and which carries a positive charge, equal and opposite to a number of electrons revolving round it at various distances or "levels". The

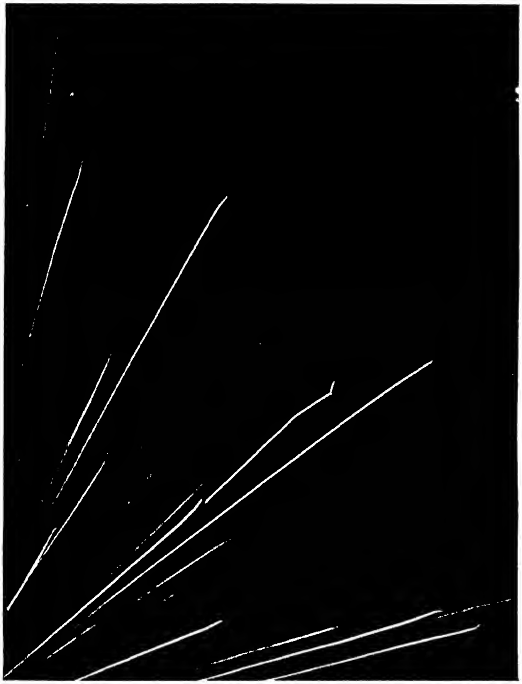
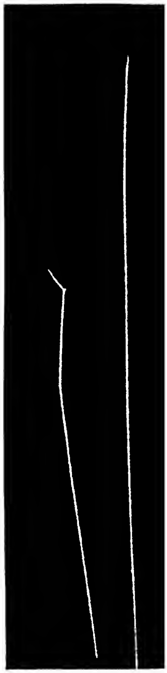


Fig. 2. Tracks of α Particles by C. T. R. Wilson

(From [illegible])



Enlargement of portion of preceding photograph

nucleus is hardly if at all bigger than the electron, so that the effective mass of the atom is concentrated into a volume not more than one-thousand billionth of the atomic volume. This we have seen is in accord with the electromagnetic theory of mass, but is completely experimental, being deduced directly from the excessive rarity with which an α-particle in its collision with an atom is deviated from its course. The light electrons in its path cannot appreciably turn it, and it is only when it meets the central nucleus of the atom it is traversing in something like a head-on collision that it is turned, and then it may be turned as much as 180°, if the atom it collides with is heavier than itself.

β-Rays.—The β-rays are responsible for most of the photographic and fluorescent effects ordinarily obtained from radioactive preparations in sealed tubes, the α-rays only being in evidence from bare preparations. They are of the same nature as the earlier known cathode-rays and Lenard-rays of the vacuum tube, which give such brilliant effects and which, when they impinge upon a dense obstacle, or "anti-cathode", produce X-rays. Both are high-speed electrons, but the β-rays travel far faster and are more penetrating than any artificially generated cathode-rays. Similarly the γ-rays, which are analogous to the X-rays and accompany the emission of β-rays, are very much more penetrating than any X-rays and are by far the most penetrating rays known. The β-rays are completely stopped by $\frac{1}{4}$ in. thickness of aluminium or $\frac{1}{16}$ in. of lead, and the fastest have a velocity within 0·4 per cent of that of light itself. On this account, they have furnished a complete proof of an abstruse theoretical prediction, arrived at more simply later by means of the theory of relativity, that mass or inertia increases at speeds comparable with that of light, and at the velocity of light should be, theoretically, infinite. The range it was possible to investigate for the β-rays of radium was up to 99 per cent, at which speed the inertia is 7·1 times that at ordinary speed, and the results over this range agreed perfectly with the formula derived from the theory of relativity.

The γ-rays are only reduced in intensity to one-half by passage through half an inch of solid lead, and they have been traced by delicate instruments after having passed through over a foot of lead or mercury. One of the greatest triumphs of modern times, which can only be alluded to in passing, is the definite proof that the X-rays and the γ-rays are in every respect analogous to the rays of light, but have a frequency of the order of a thousand times greater and wave-length a thousand times less than visible light. This is for the X-rays. The γ-rays are again much higher in frequency but to an indefinite extent. This is deduced from the power of a crystal to diffract the rays exactly as light is diffracted by a " grating ", i.e. a piece of glass or metal ruled with parallel lines, some thousands to the inch. The individual atoms in a crystal are regularly orientated in space, some ten or a hundred million to the inch, and thus the crystal acts as an appropriate grating for rays of these extremely high frequencies.

By this means not only is it now possible actually to measure up the interatomic spacing of a crystal and to determine the exact way in which the atoms are arranged in space—or what the crystallographers term the " crystal space-lattice "—but also an X-ray spectroscopy of the elements analogous to the ordinary light spectroscopy has been developed. In contradistinction to light spectra, which are usually extremely complicated, the X-ray spectra of the elements are simplicity itself, and they were discovered by Moseley to furnish the means of calling the roll-call of the elements, and of ascertaining how many places there were in the Periodic Table and how many of the places still remain to be filled. Because the frequency of the principal line of the X-ray spectrum of an element is simply connected with an integer, called the atomic number of the element, which is nothing else than its place in the Periodic Table, counting hydrogen as 1, helium 2, lithium 3, and so on up to uranium 92. This law is followed even by the exceptions to the periodic law, such as tellurium and iodine, which from the evidence of the atomic weight would be transposed and be

put into each other's families. This showed clearly that the chemical character of an element and the nature of its X-ray spectrum are not really controlled by its atomic weight, but by its atomic number. What is the atomic number?

The α-Ray and β-Ray Changes

Let us leave the question of the rays and turn to the changes which the element suffers when they are expelled. Here a very simple and suggestive law again holds. An element that expels an α-ray alters its position in the periodic table by two places in the direction of diminishing atomic number, and an element which expels a β-particle alters its position by one place in the opposite direction. Thus radium, which has the chemical character of a divalent alkaline-earth metal and is the heaviest member of the family barium, strontium, and calcium, expels an α-ray and produces a gas radon, chemically nonvalent in character and the heaviest member of the family of inert gases. It is curious to recall that the observation of the chemical resemblance between radon, or the radium emanation as it was called then, to the newly discovered inert gases of the atmosphere, was made in 1902 before even the disintegration theory had been propounded. In to-day's parlance, radium of atomic number 88 expels an α-particle and changes into radon of atomic number 86.

So far as they have been elucidated the numerous successive changes of uranium and thorium are depicted in fig. 3. The actinium series is a branch series from the uranium series, and other branchings occur towards the end of both the uranium and thorium series. With these, however, we are not specially concerned. The successive changes cover the last twelve places of the Periodic Table from that of uranium, atomic number 92, to that of thallium, atomic number 81. The diagram is best read at 45°, so that the thick lines between the successive places are vertical. The thin lines at right angles to them represent the atomic weights. The α-ray changes in which a helium atom of mass 4 with two positive

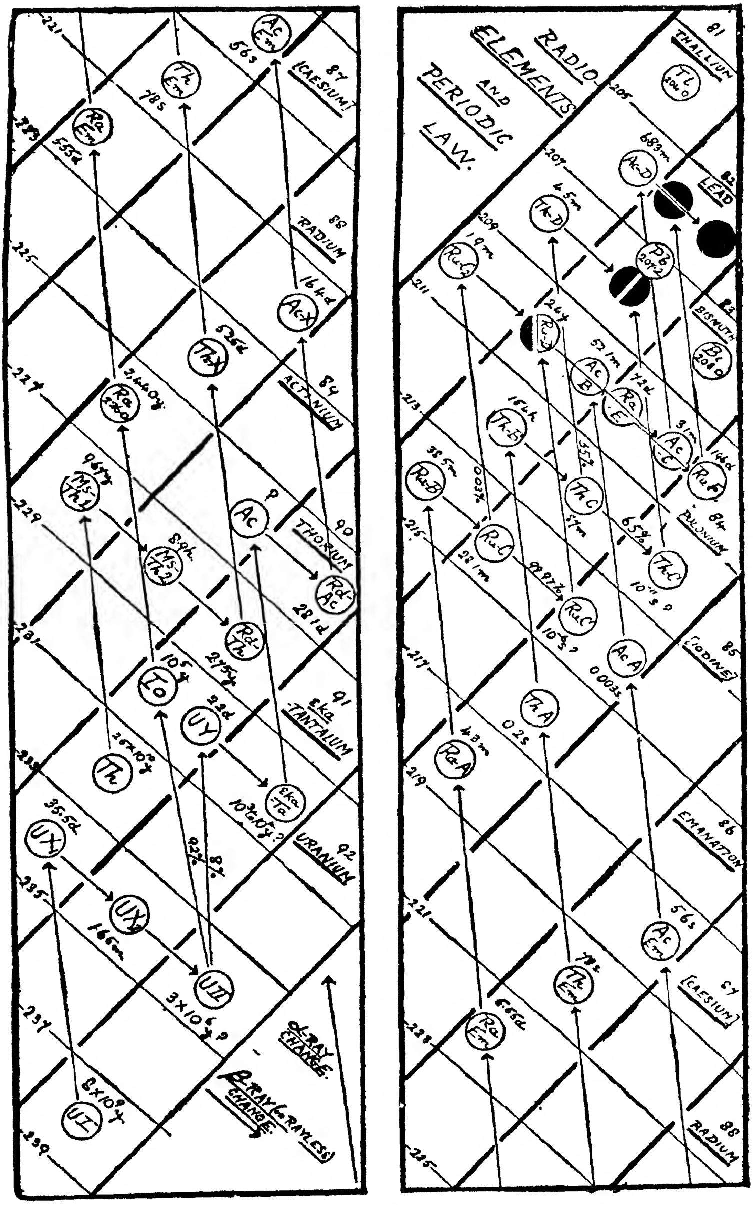

RADIO ELEMENTS AND PERIODIC LAW.
THALLIUM
LEAD
BISMUTH
POLONIUM
(IODINE)
EMANATION
(CAESIUM)
RADIUM
ACTINIUM
THORIUM
EKA-TANTALUM
URANIUM
α-RAY CHANGE.
β-RAY (or RAYLESS) CHANGE.

Fig. 3

charges is lost are represented by the long arrows pointing to the left. The β-ray change in which an electron of negligible mass carrying one negative charge is lost is shown by a short arrow pointing upwards and to the right. The changes start from uranium I (UI) in the bottom right-hand corner, and from thorium (Th) in place No. 90.

A glance at the diagram (fig. 3) is sufficient to show that not infrequently after one α- and two β-ray changes the element finds itself back in the place it started from. Also that in several of the places there are several different products of more than one series. Thus the first product of uranium I by an α-ray change is uranium X_1, which is in the same place as thorium, radiothorium, ionium, uranium Y, and radio-actinium. *All of these different elements occupying the same place in the Periodic Table are absolutely identical in their chemical properties*, though completely distinct in their radio-activities. This is how isotopes came to be discovered, the word *isotope* signifying " the same place ". Chemical methods of analysis would entirely fail to resolve a mixture of such isotopes, but since in these cases the various isotopes are produced from different substances and are changing in different ways and at different rates, they become individually knowable. This was the first indication that the ordinary chemical elements may not be homogeneous substances, but mixtures of isotopes, chemically alike, but different in atomic weight and other respects.

This matter is so important in the light it threw on the nature of the chemical elements that a further illustration may be taken. Thorium of atomic number 90 expels an α-particle and produces mesothorium 1 which has an atomic number 88, and *chemically* is absolutely identical with radium, though in its radioactive properties totally different. Then mesothorium 1 expels a β-particle, producing a short-lived product mesothorium 2, and this expels another β-particle and produces radiothorium. By the rules the element of atomic number 88 changes through 89, a place in the Periodic Table occupied by another radioelement actinium, to 90, the place

occupied by the original thorium. Mesothorium 2 is chemically identical with actinium and radiothorium with thorium, though their radioactive constants and characters are totally distinct. So for every one of the forty individual changes, as was borne out by the very careful chemical work on the radioelements of Fleck in the writer's laboratory, the above simple rules are obeyed. This generalization, which was also arrived at by K. Fajans and A. S. Russell, was prior to Moseley's work already referred to. The meaning of the successive places in the Periodic Table and of atomic number was clear. The α-particle carries two positive charges and the β-particle one negative charge. The atomic number of an element, and its order in the Periodic Table, is the number of + charges on the central atomic nucleus, and this is the same as the number of electrons circulating round it in the neutral atom. When a helium atom carrying two + charges is expelled from the nucleus in a radioactive change, the positive charge is reduced two units, and the atomic number is reduced two units. When a negative charge is expelled from the nucleus as a β-particle, the + charge of the nucleus is increased by one unit and the atomic number of the element by one unit. But perhaps the most important as it was the most revolutionary and upsetting of all the surprises of radioactivity concerns the nature of the chemical elements in general.

Isotopes

The nuclear theory of atomic structure of Rutherford, based on the experiments of α-ray scattering, and largely developed by N. Bohr, in so far as concerns the external rings or shells of electrons, and the question how the various types of spectra arise therein, has the great advantage that it gives a clear and precise picture of the difference between a chemical change and a transmutation. The former, as will be more nearly considered in a later section, is due to changes in the outer electrons without any corresponding change in the material nucleus of the atom, but the latter is due to a

fundamental change of the nucleus. In radioactivity, the material α-particle expelled *must* come out of the nucleus, if only because there is no other material in the atom from which it could come, and the β-particle no less certainly is an electron from the nucleus and not from the outer orbits. So that when one α- and two β-particles are successively expelled in any order in three consecutive radioactive changes, and this is a very common sequence, the net + charge of the nucleus which fixes the atomic number and the number of the electrons in the outer orbits reverts to what it was at the start, and in consequence the chemical character also reverts. Thorium after three such changes produces radiothorium, and—at the end of the series—after three such changes, radium D or radio-lead produces lead. But this chemical identity is not confined to members of one series, it applies whenever two products have the same atomic number. Thus, thorium in an α-ray change produces mesothorium chemically identical with radium, and the latter is produced in an α-ray change from ionium, a radioelement chemically identical with thorium and itself a product of uranium in an α-ray change. It was abundantly clear from these and similar examples that chemical character is wholly due to the external electrons, and that, so long as these are the same, the chemical characters are indistinguishable, even though the nuclei are totally different. In other words the chemical nature of an element is solely a function of the atomic number and this is the net + charge of the nucleus, independent of its constitution and even of the total number of + and − charges in it. The same is true of the spectra, not only the light but also the X-ray spectra. Hence there came the recognition that different elements could occupy the *same place* in the Periodic Table, and they were therefore called *isotopes*. Though no chemical analysis would separate them, their atomic masses need not be the same, and the atomic weight determined by chemical means might be merely a mean value dependent on the several atomic weights and the proportion of the different isotopes. If substances so different

as ionium and thorium, or mesothorium 1 and radium, once mixed, could never again be separated by chemical means, what guarantee was there that our ordinary non-radioactive elements were homogeneous and not simply a mixture of isotopes?

The Atomic Weight of Lead

For long it had been suspected that the final product of the disintegration of uranium was lead, because that element is a constituent of all radioactive minerals in proportion usually the greater the older the rocks from which they are derived. But as to the final product of thorium there was no knowledge. By the application of the rules discussed it was found that the final products in both series must fall in the place of atomic number 82 and be isotopes of lead, the element occupying this place, but that whereas the atomic weight of ordinary lead is 207·2, the atomic weight of lead from uranium should be 206, and the atomic weight of the lead from thorium should be 208; because uranium of atomic weight 238 expels, in all, eight α-particles of mass 4, and thorium of atomic weight 232 expels six such. A very interesting test was thus possible.

The atomic weight of lead derived from the purest thorium minerals has been found experimentally to be as high as 207·9, and that of the lead from the purest uranium minerals was found to be 206·05. Such a difference of atomic weight for the same chemical element obtained from different sources had often been looked for but had never before been found. At the same time it was found that the atomic weight of ionium, the direct parent of radium, was less than that of thorium by about the expected difference of two units, and this is the second case of this kind.

Aston's Work

What followed reads almost like fiction rather than a solid scientific achievement. We have seen that the new physical method of determining atomic weight should be capable of distinguishing between atoms of the same chemical character

but of different atomic mass, i.e. between isotopes. And, already in 1913, when the subject was still fresh, Sir J. J. Thomson and F. W. Aston had by this method found in atmospheric neon, of atomic weight 20·2, a mysterious companion of atomic weight some two units higher, but all attempts chemically to separate the two failed, though an elaborate fractional diffusion was partly successful in producing a slight difference in density.

After the war, Aston very greatly improved the method of positive-ray analysis used. Making a survey of as many as possible of the known elements, he showed that only about one half of them were homogeneous, and that the other half consisted of mixtures of two or more isotopes of different mass. Thus chlorine, of atomic weight 35·46, is a mixture of two isotopes of atomic masses 35 and 37 respectively. The elements which are homogeneous comprise helium, carbon, nitrogen, oxygen, fluorine, sodium, aluminium, phosphorus, and sulphur, and these are the ones for which the atomic weight is almost integral. The mixtures of isotopes comprise magnesium, neon, silicon, chlorine, zinc, and mercury, the last with no less than six isotopes, and these are the elements with fractional atomic weights. But the atomic weights of the separate isotopes, determined to 1 part in 1000 by this method, prove to be in almost every case nearly exact integers, all expressed on the basis $O = 16$. Bromine is an interesting case, because here the atomic weight is nearly the integer 80, but it is made up of two isotopes of atomic weights 79 and 81 in nearly equal proportion, no atom of weight 80 being present.

The sole marked exception is hydrogen itself. This is homogeneous, but its atomic weight, 1·0075, definitely departs from the whole number when compared with helium 4 or oxygen 16. The proof of the whole-number law is one of the most important consequences of the study of isotopes. At the same time, for the elements of higher atomic weight than 50, there is some recent evidence that it is not always strictly true.

The Einstein Relation between Mass and Energy.

Prout's hypothesis in a new form is revived by these results. The general idea is that the atomic nucleus is built up out of hydrogen nuclei and electrons, the former in excess, and that the difference between the numbers of the two kinds represents the atomic number. For the elements up to calcium 40, atomic number 20, there are usually twice as many of the former as the latter, but after this to uranium 238, atomic number 92, the proportion of electrons somewhat increases. We have seen that the nucleus is excessively minute, and therefore the two kinds of oppositely charged particles in the nucleus must be exceedingly closely packed. This brings in an effect on the mass. The theory of electromagnetic mass indicates that the mass of two oppositely charged spheres will be diminished by close packing together, and that, as the two attracting charges approach, potential energy will be turned into kinetic energy and will leave the system. The theory of relativity, on the other hand, discloses a definite simple general relation between the loss of mass and gain of energy. According to it, mass is only conserved if the energy of the system is constant, and, conversely, energy is only conserved when the mass of the system does not change. If either mass or energy suffers change the other alters concomitantly in such a way that for each unit of mass disappearing there is a production of energy equal to that of twice the mass moving at the speed of light. It would be idle to pretend that this, at present, purely mathematical deduction has the same validity as those predictions of the theory of relativity that have been put to experimental test. But it serves to explain well the atomic weights. In the hydrogen nucleus there is no electron, but when four are closely packed together with two electrons in such a way as to form a stable arrangement and give the helium nucleus, as is diagrammatically illustrated in fig. 4 (p. 395), the system must give up energy and lose mass. Thus the atomic mass of helium 4 is less than that of its components, $4 \times 1{\cdot}0075 + 2 \times 0{\cdot}00055$,

by 0·031, and this loss of mass, in the formation of 4 gm. of helium from hydrogen, is equivalent to the energy emitted in the combustion of eighty tons of coal. Radioactivity, in which helium is expelled as the α-particle, but never hydrogen, indicates that the helium nucleus is a subconstituent of the nuclei of the heavy atoms, and the integral character of the atomic weights, on the basis He $=$ 4, is to be explained by supposing that after the initial packing into helium nuclei, the further effect resulting from the assembling of these nuclei cancels out or is compensated for. It must be noted that it would be of opposite sign to the first effect. If, for example, the oxygen nucleus is regarded as built out of four ready-made helium nuclei, it would be definitely heavier than 4×4. It is supposed, then, that for all the elements the net loss in mass through the packing of opposite charges is proportional to that which occurs in helium. This integral relationship may reveal some unknown fundamental principle of nuclear constitution, but, on the quantitative side, the explanation attempted is of course merely a restatement of the experimental fact.

The Einstein relation connecting the laws of conservation of mass and energy provides a colossal and hitherto unsuspected source of energy in cosmical evolution. In modern cosmogony it is this source which is appealed to in order to account for the evolution of solar and stellar energy over astronomical epochs. But, as has been indicated, it has not yet the definite experimental foundation and justification of the kind which pre-eminently distinguishes most of our modern views on the nature of matter. It is of interest to note that the energy above calculated as being evolved in the formation of the gram-atom (4 g.) of helium is exactly the same as that evolved in the disintegration of the gram-atom (226 g.) of radium. So that the energy of the latter would be accounted for on the Einstein relation if the lead and helium produced weighed 0·031 g. less than the 226 g. of radium started from.

Chemical Consequences of the Electron Theory

Let us now consider somewhat more nearly the chemical character of the various elements and to what it is to be ascribed. Though by the foregoing discoveries the chemical atom suffers a definite resolution in that in its normal neutral state it must be regarded as a compound of atoms of electricity with positive ions, this resolution is, precisely as was the case in the early interpretation of stellar spectra, of far less fundamental character than was once loosely assumed. The positive ions constitute still an unresolved material part of the atoms, and problems such as those embraced by Prout's hypothesis remain unchanged. Matter in mass loses electrons to some slight extent when it is simply rubbed, as in the production of frictional electricity. But the same type of action occurring between the individual atoms is responsible for chemical change. Davy's dictum, that the forces of chemical affinity and electricity are one and the same, takes the more precise form that chemical affinity is due to an interaction between the atom of one element and the electrons in the atom of another. But only certain of the electrons in the system external to the atomic nucleus partake in the action. For the non-valent elements of the zero family the electrons form a stable and symmetrical arrangement without external affinities, and hence these elements form no compounds and exist always as monatomic molecules. All the other elements in the various groups or families of the Periodic Table may be compared and contrasted with these zero elements. When the number of electrons in the external system exceeds somewhat the number for the zero element, the element is electropositive or basic, and when it is somewhat below that number it is electronegative or acidic. In the early part of the table the number of elements in the period before the sequence recommences is eight, in the later part eighteen (p. 363). Thus in the early part eight electrons enter into a stable configuration or system with the nucleus without any unbalanced residual field of force of an external character. In passing through the period from each element

to the next, as the atomic number increases unit by unit, one electron is added to the external system and one equivalent positive charge to the nucleus. At each zero element—at helium, atomic number 2, neon 10, argon 18, krypton 36, xenon 54, and radon 86—the electrons form with the nucleus a completely self-satisfied system.

The tendency of the atom to form such a completed self-contained internal system is the real cause of the chemical affinity and valency of the elements.

An atom with more than this number tends to lose them if it can and to become a positive ion, whereas an atom with less than this number tends to gain them if it can and become a negative ion. So then when an atom of sodium, atomic number 11, meets an atom of fluorine, atomic number 9, the nearest zero element being neon 10, the former gives up its electron to the fluorine and becomes a sodium ion Na^+, with a nuclear charge of $+11$, but with only the 10 electrons required for the electronic system of the neon atom, and the fluorine atom becomes a fluorine ion F^-, with a nuclear charge of $+9$ and the same electronic system as the neon atom and the sodium ion.

The periodic complete absorption, as it were, of the electrons in the internal economy of the atom at each zero element, accounts for the important fact, already alluded to, that with increasing complexity no new chemical functions manifest themselves, but rather a certain sequence of functions is periodically repeated afresh. All the elements in one family of the periodic table have similar numbers of chemically valent electrons and similar, though not identical, chemical character, by far the greater part of the electrons in most cases having gone to produce internally satisfied systems, thus ceasing to exert much external influence on other atoms.

In passing through the elements in the periodic table, from the family of inert gases of zero valency, say from neon, the succeeding elements, sodium, magnesium, aluminium, and silicon are capable of losing one, two, three, and four electrons to give their positive ions, Na^+, Mg^{++}, Al^{+++}

Si^{++++}, though for the last the tendency to lose electrons is becoming very feeble. After that we come to phosphorus, sulphur, and, lastly, chlorine, before reaching the next inert gas, argon. For these the character has changed. They tend rather to take electrons than to lose them and to form the negative ions P^{---}, S^{--}, Cl^{-}, and are classified as acidic, or electronegative, in contradistinction to the first-mentioned basic, or electropositive, elements. The great advance in our knowledge of the different types of spectra emitted by the same element, already referred to, is essentially that each stage of ionization of an atom is associated with a distinct spectrum. Thus in addition to that produced by the neutral atoms of silicon Si, Fowler has shown that there are three others, corresponding with Si^{+}, Si^{++}, Si^{+++}. An electron uniting with a singly charged silicon ion to give the neutral atom gives an entirely different set of lines to that produced when it unites with a doubly, trebly, or quadruply charged silicon ion.

Broadly, two classes of chemical change are distinguishable, those on the one hand that are usually comprised in mineral or inorganic chemistry, which deals with salts, acids, and bases, and those that occur among the compounds of carbon, in what is termed organic chemistry. More correctly, the distinction is between two classes of substances, the electrolytes and non-electrolytes. The electrolytes conduct the electric current in the state of solution, or when melted, and suffer thereby decomposition into their constituents, which make their appearance at the electrodes, where the current enters and leaves the liquid. From the nature of the phenomenon and other independent evidence, Arrhenius in 1883 boldly advanced the, then, very startling view that electrolytes in solution are already more or less dissociated into oppositely charged ions, and the function of the electric current is merely to direct these ions to the opposite poles, where they yield up their charges and appear as the products of the electrolytic decomposition. Common salt in solution, or melted, is not mainly sodium chloride NaCl, but exists

as a mixture of positive sodium ions Na^+ and the negative chlorine ions Cl^-. The present view goes much farther than this. The act of combination of sodium with chlorine is regarded as essentially the pilfering of an electron from the neutral sodium atom, which, by reason of its electropositive nature, keeps but a slight hold upon it, by a chlorine atom, which as an electronegative element possesses a powerful affinity for another electron. The combination is thus not between the atoms at all, and there is no individual bond of union between them. In the liquid condition the two kinds of ion move freely and independently like the molecules in a mixed liquid or gas, subject only to the statistical requirement that equal numbers of each must coexist. We have seen that it is quite impossible for ions to exist in any quantity without a similar number of the opposite kind, because of their powerful mutual repulsion. In sodium chloride, though the individual ions are not joined together, for the above reason equal numbers of the two kinds must coexist, kept together by the powerful electrostatic attraction of the opposite charges. In the crystalline state there is still no definite bond of union between the individual ions. They are anchored in the crystal space-lattice in definite relative positions with regard to one another, but in such a way that any one of six symmetrically placed ions of the one kind could equally well be regarded as the partner of any ion of the other kind.

In organic compounds and non-electrolytes, which do not conduct the electric current with electrolytic decompositions, there is actual individual linkage of the constituent atoms of a permanent kind, as is represented in the usual structural formulæ of the chemist. Here the process of electron-robbing does not go so far. The electronegative atom establishes a lien on one or more of the electrons belonging to the electropositive atom, whereby it or they are shared by both. This, in a way not yet completely elucidated, constitutes the chemist's bond of chemical affinity or valency.

There is one rather interesting point. Although the inert gases show no chemical valency, yet they all possess external

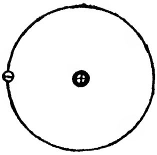
systems of electrons, which it might be expected would be shorn off by agencies more powerful than chemical affinity. Thus the α-particle expelled in radioactive changes is a helium nucleus, the two electrons which accompany it in the neutral atom having been shorn off in the atomic explosion.

It is significant that, in chemical character, helium is non-valent, and no chemical affinity is sufficiently powerful to rob it of its electrons. From this and also from some of the evidence on stellar evolution, it may be predicated that ordinary chemical changes are not very profound, and that, without trenching upon any fundamental transmutation, more intense orders of chemical affinity than any yet recognized, associated with the inner layers of electrons of the atom, ought to exist latent in matter. In other words, between radioactive and chemical change intermediate types, not involving the actual identity of the atom, but far more powerful than chemical change, ought to be possible.

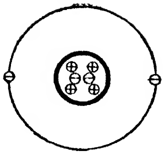
The Modern Picture of Atomic Structure.

We may draw together in a pictorial form the modern ideas of the structure of the atom which have gradually crystallized out of the whole of the evidence here briefly reviewed. It will be sufficient to depict the structure of some of the lighter atoms, as for the heavier and more complex structures, although the same general ideas hold, there is as yet little evidence. Also, merely for the purpose of convenience, the external system of electrons must be represented by rings containing usually many electrons in the same orbit. In the actual theory of this part of the structure, as developed by Bohr from spectroscopic evidence, each electron has a circular or elliptic orbit to itself, with very definite particulars as to its diameter, eccentricity, and position relative to the other orbits. But into these refinements we cannot here enter.

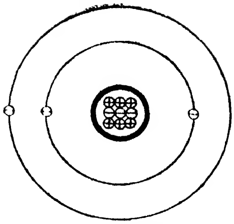
For the purpose of the figure, the hydrogen ion or proton is represented by a plus sign, and a negative electron by a minus sign, each circumscribed by a circle. The inner thickly-drawn circle represents the nucleus, and the outer



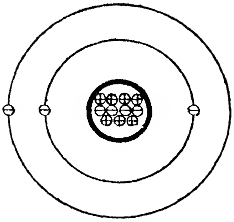
1. Hydrogen
At. No. 1. At. Wt. 1



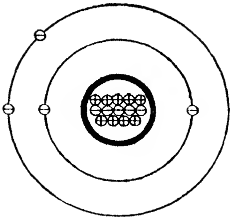
2. Helium
At. No. 2 At. Wt. 4



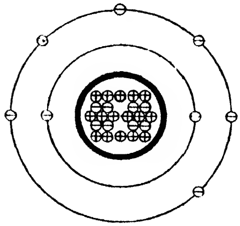
3. Lithium
At. No. 3. At. Wt. 6



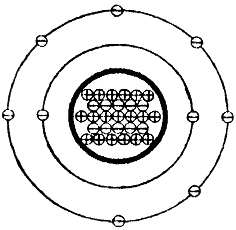
4. Lithium
At. No. 3. At. Wt. 7



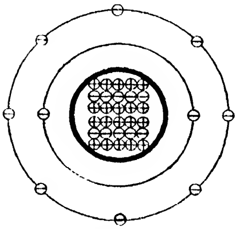
5. Beryllium
At. No. 4. At. Wt. 9



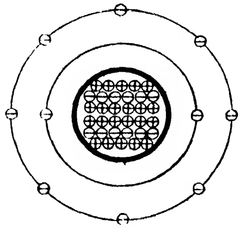
6. Oxygen
At. No. 8. At. Wt. 16



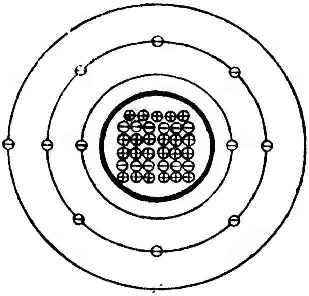
7. Fluorine
At. No. 9. At. Wt 19



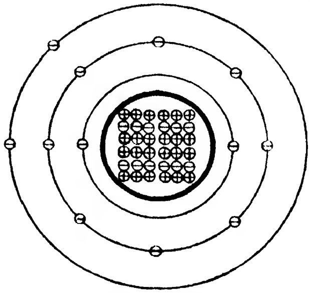
8. Neon
At. No. 10. At. Wt. 20



9. Neon
At. No. 10. At. Wt. 22



10. Sodium
At. No. 11. At. Wt. 23



11. Magnesium
At. No. 12. At. Wt. 24

Fig. 4

circles the external electrons, the outermost circle containing the valency electrons.

In the drawing (fig. 4), No. 1 represents the hydrogen atom, consisting of a single proton and a single electron revolving round it. Drawn to proper scale, if the hydrogen atom, i.e. the orbit of the electron, were of the same diameter as the earth, the diameter of the electron would be about 100 yards, and the diameter of the nucleus about 2 inches. No. 2 represents the helium atom. Here four hydrogen nuclei have been packed into the nucleus with two electrons, giving an atom of mass 4 and net nuclear charge or atomic number 2. Nos. 3 and 4 in the same way represent the two isotopes of lithium, of atomic number 3 and atomic masses 6 and 7 respectively. A new orbit containing the single valency electron has been formed outside the orbit containing the two external electrons in the helium atom. In No. 5 we have the beryllium atom of atomic number 4 and atomic mass 9. Beryllium is divalent, and there are now two electrons in the outermost ring. So the period proceeds regularly, boron having three valency electrons, carbon four, and nitrogen five. These last three are not shown. No. 6 represents the oxygen atom with six external valency electrons, functioning usually as a divalent negative element, preferring to add two more electrons to its outer ring to complete its octet. With fluorine, No. 7, only one more electron is needed, and this element is a strong monovalent acidic element. The next two, Nos. 8 and 9, represent the two known isotopes of neon, of atomic number 10 and atomic masses 20 and 22 respectively. Here we have the outer ring complete with eight electrons, and the element is therefore non-valent. Sodium, No. 10, and magnesium, No. 11, are the analogues of lithium and beryllium, built on the neon rather than on the helium model. Magnesium has three isotopes of atomic masses 24, 25, and 26, but only the first is shown. Thus in a very tentative manner we envisage the formation of the whole periodic system.

Such dynamic models of the atom as the above do not sufficiently represent many of the facts of chemistry. The

complicated Bohr model, in which the various electronic orbits are worked out in accord with certain dynamical assumptions for the purpose of accounting primarily for radiation and the frequency of the lines in the spectral series of the elements, misses what is impressed upon all who have studied the solid and crystalline state of matter. Here we have to do with hard substances possessing a certain fixity and definiteness of form and arrangement in space, the properties of which depend on what may be termed the architecture of chemical compounds

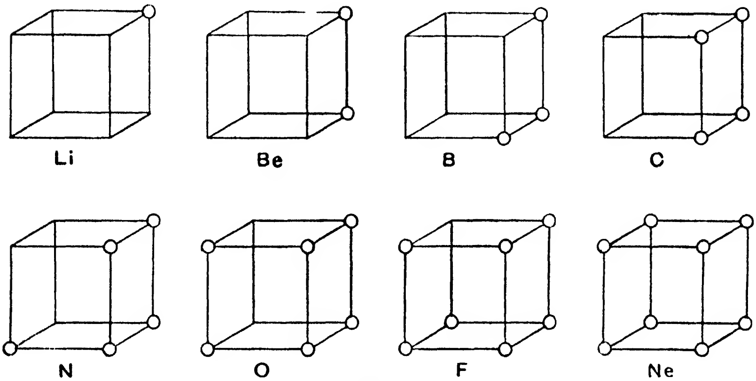


Fig. 5

and crystals. For this reason simple alternative ways of representing the atom have come into use. If we deal with the light elements the number of electrons that separate an element from its nearest analogue is eight. Thus the atomic numbers of lithium, sodium, and potassium are respectively 3, 11, and 19. In the Lewis model this octet of electrons is represented as occupying the corners of a cube, and fig. 5 represents the outer or valency system of electrons only in the first short period of the elements. On this scheme, the formation of a non-electrolyte or non-polar compound, such for example as the formation of the fluorine molecule F_2 from two fluorine atoms, is depicted in fig. 6. Here a pair of electrons is shared by both atoms, so that each now has the completed octet it

seeks to obtain, and this shared pair of electrons constitutes the single bond of valency of the chemist. Whereas the formation of an ionized or polar compound, which is an electrolyte and which, therefore, exists in the form of separate ions held only by their general electrostatic attraction, is shown in fig. 7.

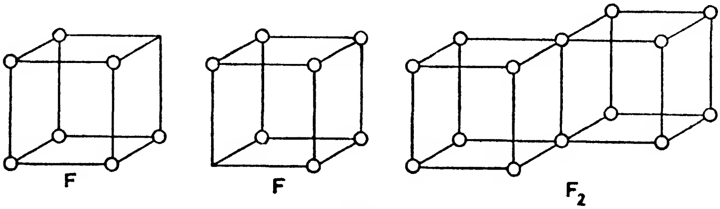


Fig. 6

Here the union of sodium with fluorine to sodium fluoride is depicted. The external electronic systems of the sodium and the fluorine ions are identical, but the one contains a nucleus of eleven and the other a nucleus of nine positive charges, each with two electrons outside the nucleus but inside the cube. Thus the sodium ion has one more positive charge than

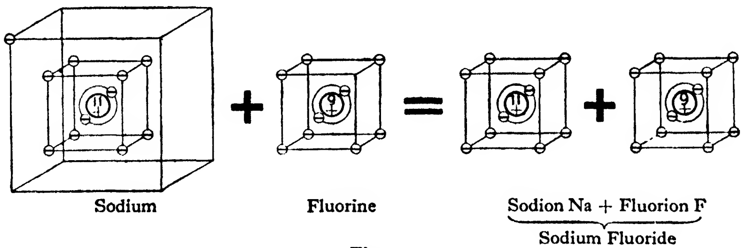


Fig. 7

negative and the fluorine ion one more negative than positive, though their external structures are similar. Owing to the stronger central charge the external octet of electrons for the sodium ion would naturally be smaller in diameter than for the fluorine ion, but no attempt to represent the relative scale is made in any of these diagrams.

Artificial Transmutation

One of the most important results that has emerged from the minute study of the bombardment of the various elements with α-particles is that, in the rare event of a direct hit on the nucleus, the atoms of certain of them are disrupted, with the emission of a high-speed hydrogen nucleus. This nearly approaches an artificial transmutation, though it depends on the natural transmutation of radium in the first instance. That the particle expelled is really a hydrogen nucleus has been established by the physical method of atomic weight determination described, and, of course, the greatest precautions have to be observed that no water or other compound of hydrogen is present in the substance bombarded. One of the lines of evidence that seems to exclude the possibility that the source of hydrogen is extraneous is that in certain cases, as, for instance, aluminium, the kinetic energy of the hydrogen expelled is greater than that of the bombarding α-particle. The elements of odd atomic number—boron, 5; nitrogen, 7; fluorine, 9; sodium, 11; aluminium, 13; and phosphorus, 15—all eject high-speed hydrogen nuclei under these conditions, whilst the intermediate elements of even number either do not furnish them, or, if they do, give particles of much lower velocity. It is supposed that, in the "odd" elements, the nucleus contains, outside of the main central system, a hydrogen nucleus separated as a satellite, and that it is these satellites which are detached in a violent encounter with the α-particle.

The amount of hydrogen thus produced is so infinitesimal that it is completely beyond any possible method of detection, except, as a radiant particle, by the scintillation it produces on impinging on a screen of zinc sulphide. Owing to its smaller mass, this is not so bright as in the case of the α-particle itself, but the " H-particle " travels much farther and can be detected at distances from the source many times greater than the α-particle. Only an almost inconceivable proportion of the atoms struck is disrupted—for example, in the case

of aluminium, it is estimated that the proportion is 1 in 100,000,000,000.

More recently, and actually at the time of writing (July, 1924), Professor Miethe of Charlottenburg has reported an actual transmutation of mercury into gold in the ordinary mercury lamp used to produce ultra-violet light, when working at a voltage—above 180 volts—somewhat higher than that usually employed. Were this correct, it would be the first case of a real *artificial* transmutation. It cannot of course be accepted until it has been established by independent observation under the most rigorous crucial conditions.

But it may serve, meantime, to draw attention to an apparently necessary deduction from our present nuclear theory of atomic structure, which, hitherto, has not been pointed out. When the α-particle approaches a nucleus, both bodies being positively charged, an extremely powerful repulsion between them exists. But when an electron, instead of an α-particle, is fired at a nucleus, so long as it possesses sufficient initial energy to pierce the outer electrons which guard the nucleus, it will be subjected, once within, to a powerful attraction by the nucleus. It is, therefore, in the present state of knowledge, necessary to suppose that a minute proportion of the bombardments result in the electron actually striking the nucleus and being captured by it. Now we have, in the β-ray change, an example of the precisely opposite process. The nucleus expels an electron and the element suffers an increase of one in atomic number. So that the result of a direct hit of a high-speed electron on an atomic nucleus, and its capture by it, must be to lower the atomic number of the element by one. In the case of mercury of atomic number 80, an infinitesimal portion of the atoms should be transformed into an isotope of gold, the element of atomic number 79. This should be quite general for all the elements, but the case of gold and mercury offers probably the most favourable possible example to test experimentally, owing to the peculiar ease with which mercury may be purified and to its unique electrical behaviour, which is turned to account in the mercury

vapour lamp. Indeed, prior to Professor Miethe's announcement, the writer was himself planning an experimental test of the point in question.

Incidentally, it may be mentioned that mercury, according to Aston's work, contains at least six isotopes of atomic weight between 197 and 204, the chemical atomic weight of gold being 197·2. Mercury is the one element which, so far, has been partially resolved into its isotopes, by a beautiful physical method involving the principle of unidirectional fractional distillation, devised by Hevesy, who by this method has succeeded in obtaining fractions both slightly lighter and slightly heavier than the original mercury. It is known that the densities of isotopic elements are proportional to their atomic weights, and the method of separation depends on the fact that the lighter atoms, by the law of equipartition of energy, are moving somewhat faster than the heavier and so escape during unidirectional volatilization rather more easily than the heavier atoms, the volatilized part being lighter than the part not distilled.

Is the Idea of Evolution applicable to Matter?

The world of physics and chemistry is, fundamentally, the non-living or inanimate external world, and the student of it must always be on his guard against anthropomorphic notions and the too literal acceptance of mere analogies or supposed analogies that invade it from the world of life. The doctrine of evolution has been derived from our knowledge of living organisms, and as such can apply strictly only to the world of life. The living world is dominated by a principle which finds no counterpart in that of pure physics and chemistry, leading to a gradual and orderly growth and development of the complex from the simple. It is a new principle superimposed upon the inanimate world rather than affecting its fundamental basis. The continuous guidance and direction of physico-chemical processes, which differentiates the living from the dead, may be likened to the touch on the hair-trigger of a purely inanimate but powerful gun, or the

twist on the steering-wheel of a leviathan. Through a mastery, conscious or subconscious, of the mechanisms involved, life consists in the direction of purely inanimate events and processes to vital ends. One may argue thence to the subconscious control of the involuntary processes of the living body, and from the living individual to the race, to the continuous change and progressive improvement of the species, and to all the varied phenomena of life, upon which some form of continuous direction is imposed. But it is the merest obsession to extend such ideas to the inanimate world. Growth, reproduction, orderly progressive evolution are absent here. True, it is more natural to regard the complex as made from the simple than the converse, and the term evolution in physics and chemistry implies little more than this mental axiom, but there seems no reason to connect the simple with the past and the complex with the future. The problem is here the world as it is. The truism that, without consciousness, no knowledge of its existence would exist does not impress the scientific mind. It is impossible for such not to believe that the inanimate world not only exists but actually did exist long without life, and that the latter is an interloper, with peculiar requirements and ideas, as regards creation, origin, growth, and purposeful development, which it applies unintelligently, not only to its own world, but to the eternal and independently existing world in which it lives.

We can thus sum up the evidence for and against the application of evolutionary ideas to the inanimate world. On the one hand we know now that matter is almost infinitely more diverse in character than hitherto supposed. Not only are there still eighty-seven fundamentally different kinds resisting artificial transmutation, but each of those kinds may be a group of an indefinite number of fundamentally different things superficially alike, but as regards the nucleus of the atom different. We can readily imagine new kinds of differences in the nucleus which no present experimental method could reveal if they existed. At the same time the modern interpretation of the Periodic Law shows that the elements,

so far as we have penetrated their mysteries, are a consequence of certain fundamental relations between electricity and matter of a formally numerical character. On the other hand we can watch, in one limited field, an actual *devolution* of the two heaviest elements through twelve successive places in the Periodic Table in zigzag course, till the process comes to a stop at lead. We have the explanation of why transmutation has proved an accomplishment beyond our power. In the nuclear conception of the atom we see, as it were, the material heart of the atom so well guarded by electronic defences, that it is well nigh impossible to attack it by our present methods. At the same time, as the experiments of Rutherford with the bombardment of atoms by α-rays, and those of Miethe, in which an actual transmutation of mercury into gold is reported, we are beginning to realize that although, in the mass, transmutation of one element into another may long elude us, yet on an infinitesimal scale, for that almost inconceivably small proportion, represented by the ratio of direct hits on the nucleus to misses, transmutation may indeed be a possibility, if not an actual hitherto undetected accompaniment of many processes. In this respect our views are in a state of rapid development.

Evolution of thought? Yes! This account is nothing else than a record of the progressive and systematic development by which *our knowledge of* the known universe has come to be what it is. Evolution of species, and the gradual growth by which living beings have come to be what they are? It is a most natural inference, though as yet there is no direct evidence of the change of one species into another, and, in this respect, we know more about the devolution of matter than about the evolution of species. The present universe is undoubtedly a consequence, but can it be really regarded yet as an evolution from some pre-existing *simpler* order? Is it not that the living mind seeks to impose itself, and its ideas of birth, growth, and purposeful development, mysteries akin only to life, upon the eternal fabric which it animates? Can anyone honestly see even a trace of that consecutive

progress resulting from an arbitrarily varied choice—be it conscious or subconscious, natural, human or divine—which characterizes the world of life, really reflected in the ways of the material universe? That world is other, and alike those who would bring it under the rule of life and those that would evolve from it that rule stultify the fruits of learning and make of real knowledge a fantastic whim.

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CHAPTER XI

Time and Space

In attempting to give a systematic account of the world in which we find ourselves, the order of events and objects in Time and Space will be found to be one of the most important problems demanding our consideration.

Man's attention must have been directed very early to the subject of time, while the science of geometry still preserves in its name, γεωμετρία, a record of its early use in the measurement of land.

In ancient Egypt the annual overflow of the Nile and the consequent obliteration of landmarks appears to have directed attention to the importance of geometry, which was later seized upon and converted into an abstract science by the subtle intellect of the Greeks.

It is to be noted that though this abstract science had its origin in purely physical problems, and was consequently extremely well adapted for dealing with such problems, yet, as a logical system, it was and is independent of any particular physical application. The usual application is not the only possible one, as is seen when we consider, for example, the fact that any geometrical theorem concerning points and lines on a plane sheet of paper has an application when the paper is rolled up into a spiral.

Not only is this the case, but the abstract logical system associated with the name of Euclid is not the only system possible, and various other systems have been investigated by geometers.

The first non-Euclidean geometry to be studied was that which was brought into prominence by the independent investigations of Lobatchewsky and of Bolyai, and, regarded simply as a logical system, it has been proved that this must be quite as consistent in itself as the system of Euclid; since any inconsistency in the former would imply an inconsistency in the latter. The system of Lobatchewsky, however, unlike that of Euclid, was not originally devised for any such purpose as surveying, and it would be extremely inconvenient for such a purpose.

The reasons for this are physical. There are certain physical facts which correspond—if not exactly, still to an extremely close degree of approximation—with the postulates from which Euclidean geometry may be built up, and these facts enable us to give an interpretation to the abstract relations described in these postulates.

The geometry of Lobatchewsky, while not so convenient as that of Euclid in dealing with these particular problems, admits nevertheless of important application in other departments.

We have referred to the fact that geometers have studied various other systems besides those of Euclid and Lobatchewsky, and one naturally desires to know what is meant by " geometry " in this extended sense of the term.

Professor Whitehead has defined geometry in the abstract sense as " the science of cross classification ".

The elements classified are generally referred to as " points ", but may be any entities which satisfy certain postulates.

With this definition of geometry one may construct " geometries " having only a finite number of elements, but these do not concern us here, being mere logical curiosities.

Those which do concern us in our attempts to map out space and time are constructed so as to involve an infinite number of elements forming some sort of continuum.

The classifications with which we are concerned, such as lines, planes, &c., depend for their definitions upon certain

relations among the elements considered. These relations must have their counterparts somehow in physical space or time if the system of geometry is to be of any use for mapping purposes.

Order in Time

It will thus be seen that the problem we are considering has a logical aspect and a physical aspect, which are independent of one another, although we are guided in our search for a logical system by a consideration of the facts of our experience.

Now among the most fundamental of these is the *order* of events in time.

What we call *now* singles itself out in the mind in a manner which is perhaps indescribable.

We speak of *now* as an *instant*, but there are innumerable instants which we experience and each of these is in its turn a *now*. Of any two of these instants which I experience one is, as we say, *after* the other. This relation denoted by the word *after* is what is called an asymmetrical relation; by which is meant a relation R, such that if B has the relation R to A then A has not the relation R to B.

It should be observed that there is no such asymmetrical relation between two points or two particles in space; for though it is possible to assign an order to them by means of some convention, yet such convention is quite arbitrary and has no special significance in the nature of things.

As to the significance of the relation of *after* as regards instants, we shall have more to say at a later stage, but at present we are concerned merely with its asymmetrical character, which is directly perceived by the mind.

But even one's very thoughts are subject to a time order, so that if one closes one's eyes and other channels of sense, so far as is possible, one still recognizes one thought as following *after* another. Let us however re-open these channels of sense and look about us.

One sees before one a complex picture which is ever chang-

ing, and, if one splits this up into component parts, one recognizes certain events in this changing picture as occurring (at least approximately) at the same instant, while others occur at different instants.

This simultaneousness, or lack of it, is an ultimate fact and must be regarded as absolute; but we must remember what things we are asserting to be simultaneous.

We are making the assertion about certain *perceptions* of a single individual.

Unless one is a solipsist, however, one believes in the existence of more than one's own self and one's perceptions, and regards these perceptions, under normal circumstances, as representing things as real as one's self, but in some sense *external*.

In pursuance of this view one naturally thinks of the assumed external events as having a time order; and the first view which one takes, and which serves for most of the purposes of our daily life, is that these external events occur at the instants at which one perceives them.

A little careful observation, however, will convince us that this is not strictly correct, at any rate for all our perceptions. If I observe a man striking some object with a hammer, then, provided I am close to him, I see the blow being struck and hear the sound of the blow practically simultaneously. If on the other hand I am at a considerable distance from him, my perception of the sound of the blow occurs appreciably *after* my visual perception of the blow being struck. Thus my auditory perception of a distant event cannot be simultaneous with that event as judged by my visual perception.

The question then naturally arises whether one's visual perception of a distant event occurs simultaneously with the event itself, and again the answer is in the negative.

The first definite evidence that this is so was obtained by Römer in 1675–6 by the observation of the eclipses of Jupiter's satellites.

There was, however, the possibility of some other explanation of Römer's observations; a possibility which practi-

cally vanished when Fizeau, in 1849, tested the matter by direct experiment.

Fizeau was able to show that, when a flash of light was sent out from the neighbourhood of the observer to a distant mirror and there reflected back to him, the instant of the return of the flash was appreciably *after* the instant of its departure.

Thus the instant at which a distant instantaneous event occurs cannot be identical with that at which it is perceived, and we perceive near and distant events simultaneously which most certainly do not occur simultaneously.

This fact cannot be ignored if we try to correlate astronomical events with one another, or with terrestrial ones; but we can and do ignore it with impunity in the ordinary affairs of daily life.

Men of science, however, concern themselves with many things whose bearing on ordinary daily life appears, at first sight, remote, but even those who neglect science are sometimes startled to find what an important bearing such things sometimes can have.

The question arises as to the theoretical possibility of identifying the instant at which a distant event takes place with that of some event close at hand.

It will be found that in all attempts to do this we meet with very serious difficulties and that this question is intimately bound up with another, namely: the theoretical possibility of identifying one and the same point of space (or of the æther of space) at different instants of time.

If this latter were possible we should be able to tell when a particle was at " absolute rest ", since it would then remain constantly at the same point of space (or of the æther).

If we imagine for a moment that we have an apparatus such as that employed by Fizeau, and that the apparatus is at " absolute rest " in this sense, and if, neglecting for the moment any difficulties which there may be in connection with the measurement of time intervals, space intervals, or velocity, we suppose that the light flash travels through space

(or the æther) with uniform velocity, then we should naturally conclude that the light took the same length of time to go as it did to return, and that the instant midway between the instants of departure and return must be the same as the instant of reflection at the distant mirror.

If, on the other hand, the apparatus with the observer is in uniform motion, say in the direction in which the light travels on its outward journey, then it would appear that the mirror retires in front of the outward going flash and the observer advances to meet the returning one, so that, the light not having so far to travel on its return as it had on its outward journey, the instant midway between the instants of departure and return would no longer be the same as the instant of reflection.

No method, however, is known by which we can distinguish "absolute rest" from uniform rectilinear motion, so that, even if all other difficulties were overcome we should still be unable to identify the instant of reflection with any instant at the sending apparatus.

If one is situated in a closed room on a boat which is moving uniformly and without vibration over a smooth surface of water, then, provided one cannot see out of the room, one has no means of detecting this motion, or of saying that the boat is not at rest.

Again, the water on which the boat floats is situated on the earth, which, relatively to the heavenly bodies, is moving in an orbit round the sun; but, apart from observation of the heavenly bodies, one does not detect this motion any more than one detects the motion of the boat when one is in the closed room.

According to the classical mechanics a system of bodies whose centre of inertia is in uniform motion in a straight line is indistinguishable, so far as mechanical effects are concerned, from a similar system whose centre of inertia is at rest.

The Michelson-Morley Experiment

Many attempts have been made to devise some optical or electrical experiment which would show the earth's absolute

motion through the æther, but all such attempts have been unsuccessful.

The best known of these is the celebrated Michelson and Morley experiment, which consisted in dividing a beam of light into two portions which travelled, the one in one direction and the other in a transverse direction, and were reflected back by mirrors.

Adopting ordinary ideas for a moment, let us suppose that the light is propagated with velocity v through the æther and that the apparatus moves through the æther with velocity u; then it is easy to calculate the time of the double journey for the two portions of the beam.

For the case of a part of the beam which travels in the direction of motion of the apparatus, the time occupied by the double journey is found to be

$$t_1 = \frac{2va_1}{v^2 - u^2},$$

where a_1 is the distance between the point of the apparatus where the beam divides and the corresponding mirror.

If a_2 be the corresponding distance for the case of the transverse portion of the beam, then we can easily show that the time of the double journey should be

$$t_2 = \frac{2a_2}{\sqrt{v^2 - u^2}}.$$

Now if the distances a_1 and a_2 be adjusted so that the times occupied by the two portions of the beam in their journeys are equal, we have

$$\frac{2va_1}{v^2 - u^2} = \frac{2a_2}{\sqrt{v^2 - u^2}}.$$

From this it follows that

$$a_1 = \sqrt{1 - \left(\frac{u}{v}\right)^2}\, a_2,$$

so that a_1 should be somewhat less than a_2.

Now the necessary adjustment can be made with extreme accuracy by means of the optical interference bands which are produced, and the remarkable fact is observed that, when the whole apparatus is caused to rotate at a uniform slow rate, the one adjustment holds for all positions. Thus the apparatus gives no evidence of the motion of the earth, although it might be expected to do so.

It is difficult to explain this result unless we suppose that the material of the apparatus contracts along the direction of its motion through the æther in the ratio of $1 : \sqrt{1 - \left(\frac{u}{v}\right)^2}$, and in fact this hypothesis was put forward by FitzGerald and by Lorentz to account for the absence of any observable effect. If, however, bodies change their dimensions in this manner when they move, and if we are unable to detect this motion, what do we really mean by a body remaining of constant length, or by its being equal in length to another body?

If the FitzGerald-Lorentz effect occurs, then the distance between the points of the most rigid of compasses will vary as the instrument is turned in different directions with respect to the earth's motion, and similarly, the shape of the most rigid material triangle will change when we try to superpose it on a material triangle of different orientation.

It is true that these changes would presumably be very minute under ordinary circumstances and could therefore be neglected, but if they are non-existent, how are we to explain the null result of the Michelson-Morley experiment; especially in view of some experiments by Lodge, which seemed to prove that the æther was not carried along by moving matter in the neighbourhood?

The limits of this article prevent me from giving a full account of the various experiments and observations which confirm the view that uniform motion through the æther cannot be detected, but only the motion of bodies relative to one another.

In addition to this we have found ourselves unable to give

any criterion by which to decide that a distant event is simultaneous with one near at hand, and even the physical properties of solid bodies which we employ in the ordinary measurement of lengths are called in question.

The great pioneers in reducing this matter to order have been Larmor and Lorentz, who showed that the electromagnetic equations could be reduced to the same form for a system in uniform motion through the æther as for a system at rest; and when Lord Rayleigh in 1902 raised the questions whether rotatory polarization is influenced by the earth's motion, and whether motion through the æther causes double refraction, Larmor, from his theory, was able to predict the absence of any effect. This was confirmed by Rayleigh's experiments.

In order to transform the equations a " local time " had to be introduced, and the question arises: what is the philosophical significance of this " local time "?

Einstein put forward the view that events could be simultaneous for one observer but not simultaneous for another, moving with respect to the first. This view, in my opinion, gives an air of unreality to the external world which, besides being utterly repugnant, is quite unnecessary.

The only simultaneousness with which one is directly acquainted, namely that of perceptions or ideas in one's own mind, is of an absolute character, as has already been pointed out.

Now let us see what Einstein actually does. If a flash of light goes out from the neighbourhood of an observer and is reflected back to him from a distant mirror, then Einstein asserts that the reflection at the distant mirror is simultaneous with an event at the sending station which occurs at the instant midway between the instants of departure and return of the light.

Apart from the difficulty of determining this instant (which Einstein supposes to be done by means of a clock), consider what this implies.

Suppose that to-day I should observe the outburst of a

new star which, in astronomical language, was distant say 100 light-years; then according to Einstein, this outburst occurred simultaneously with terrestrial events which took place before I was born. This therefore cannot be a fact of observation so far as I am concerned; so that one has no right to speak of such events as being *simultaneous for one observer*.

The actual *observed* fact would be that my *perception* of the outburst was simultaneous with other experiences occurring to-day.

On the other hand, if the simultaneousness of the events be real, then, as has already been shown, we have no method at our disposal of detecting it.

It might be urged that the above is Einstein's definition of the "simultaneousness" of distant events; but, if this be so, then the word "simultaneous" is being employed in two utterly distinct senses, which have nothing in common and may easily lead to great confusion of thought.

I ought perhaps to make it clear that I am here attacking, not Einstein's mathematical analysis, but his philosophy. The notion of "local time" as a mathematical quantity was introduced by others who did not hold that philosophy.

Minkowski made a notable advance when he showed how a sort of four-dimensional analytical geometry could be set up, in which the change from one set of time-space variables to another corresponded to a change of co-ordinate axes.

Minkowski's work was, however, purely analytical, and assumed that such difficulties as there may be in the introduction of a co-ordinate system and the application of measurement to times and lengths had been overcome.

As regards such measurement, however, there are few of us who have got Professor Einstein's childlike faith in the time-keeping qualities of clocks, and most of us find sufficient difficulty in putting our trust in them, even when they are not sent flying through space with high velocities.

Our trust in measuring rods is also shaken when we consider the existence of such a substance as india-rubber, and

reflect that it only possesses in an exaggerated degree a property of extensibility common to all solid bodies.

It will doubtless be urged that Einstein deals only with ideal clocks and measuring rods; but many of those who think that ideas of measurement form a sufficiently fundamental basis for this subject, may be shaken in their belief by the consideration of the following facts, which I must ask the reader to take on trust if he is not already familiar with them.

Theoretical Inadequacy of Usual Treatment

In the above-mentioned analytical geometry of Minkowski, which corresponds to what Einstein calls " *the restricted theory of relativity* ", there are (what, in analogy with ordinary geometry, may be called) three types of (straight) line, three types of plane, and three types of (flat) threefold.

Elsewhere I have named the lines *inertia lines*, *optical lines*, and *separation lines*.

The planes I have called *acceleration planes*, *optical planes*, and *separation planes*.

The various types of plane contain the various types of line in the following way:

$$\text{An acceleration plane contains} \begin{cases} \text{inertia lines,} \\ \text{optical lines, and} \\ \text{separation lines.} \end{cases}$$

$$\text{An optical plane contains only} \begin{cases} \text{optical lines and} \\ \text{separation lines.} \end{cases}$$

A separation plane contains only separation lines.

Now no triangle can exist all of whose sides are segments of optical lines, but triangles can exist all of whose sides are segments of separation lines or of inertia lines.

For a triangle all of whose sides are segments of separation lines we may have the sum of the lengths of any two sides greater than that of the third side; or the sum of the lengths of a certain two sides equal to that of the third side; or the sum of the lengths of a certain two sides less than that of the

third side; according as the triangle lies in a separation, an optical, or an acceleration plane.

As a result of this, *the length of a segment of a separation line between given extremities is neither a minimum nor a maximum.*

A triangle all of whose sides are segments of inertia lines can only lie in an acceleration plane, and, in this case, the sum of the lengths of a certain two sides is less than that of the third side.

As a result of this, *the length of a segment of an inertia line between given extremities is a maximum in the mathematical sense.*

Again, while we may compare lengths along the same or along two parallel optical lines, *there is no meaning either in the equality or inequality of two segments of distinct optical lines which are not parallel.*

The three statements printed in italics illustrate in a striking manner some of the more fundamental differences between the analytical geometry of Minkowski and geometry of the ordinary Euclidean type with which we are familiar.

Although the geometry of a separation plane, in which all the lines are of one kind, is Euclidean in character, the geometries of the other two types of plane exhibit features so extraordinary as to appear quite paradoxical. In ordinary geometry one does not get maximum lines joining two points, nor does one get broken or curved lines whose total length is equal to the length measured *directly* from one point to another.[1]

[1] This may easily be illustrated analytically. In Minkowski's geometry, the length of an elementary portion ds of a separation line is given by the formula:

$$ds^2 = dx^2 + dy^2 + dz^2 - dt^2.$$

Let O be the origin of co-ordinates and let P be any point on the axis of x at a distance l from O, measured, say, in the positive direction.

Let $F(x)$ be any arbitrary differentiable function of x which is continuous and single-valued, and which is equal to zero, for $x = 0$ and for $x = l$.

Now consider the space-time curve whose equations are:

$$y = t = F(x),$$
$$z = 0.$$

It is evident that this curve passes through O and P.

On hearing of these, one would naturally want to know what was meant by measuring *directly*, since one is accustomed to think of a straight line as being the *shortest* line joining two points.

So deeply ingrained was this idea that a very large number, if not the majority, of Relativists at one time actually asserted that intervals in space-time theory were minimum lengths; and though I succeeded in getting some of them to see that the length of a segment of an inertia line is actually a *maximum*, I am not aware to what extent it is even yet recognized that the length of a segment of a separation line is *neither a minimum nor a maximum.*

When, in addition, we consider the fact that there are segments of optical lines whose lengths cannot be compared with one another at all, most people will, I think, be forced to admit that the conception of an interval in Minkowski's geometry is very far from being a simple one.

Conical Order

These facts, which were pointed out in my book, *A Theory of Time and Space*, published in 1914, show that the measurement of intervals cannot be regarded as a fundamental notion in this subject.

The proper foundations from which to build up this system of geometry appear to be ideas of *order*, as has already been hinted.

In the above-mentioned work it was shown that a system of postulates could be formulated in terms of the relations of *before* and *after*, which enable us to build up the whole system

But now we have

$$dy = dt,$$
$$dz = 0,$$

and so $$ds^2 = dx^2.$$

Thus we have $ds = dx$, and so the length measured along this space-time curve from O to P is equal to the length from O to P measured directly along the axis of x. That is, it is equal to l.

Thus a space-time curve whose equations contain an arbitrary function can have the same length between two points as the direct length measured between these points, provided the latter lie in a separation line.

including ideas of congruence and measurement in terms of these relations.

The space at my disposal does not permit of giving here a full account of how this may be done, and I must refer those who are interested in the details either to the above work or to *The Absolute Relations of Time and Space*, in which I give a résumé of the argument.

I must content myself here with a very brief account of the point of view.

Although it is difficult to isolate a single instant in our consciousness, yet one knows sufficiently well what one means by the word *now* to be able to describe formally the characteristics of the order which the series of instants appears to have in one's own mind. These are as follows:

1. If an instant B be *after* an instant A, then the instant A is not *after* the instant B, and is said to be *before* it.

2. If A be any instant, there is an instant which is *after* A and also one which is *before* A.

3. If an instant B be *after* an instant A, there is an instant which is both *after* A and *before* B.

4. If an instant B be *after* an instant A, and an instant C be *after* the instant B, the instant C is *after* the instant A.

5_0. If an instant A be neither *before* nor *after* an instant B, the instants A and B are identical.

Now it has too hastily been assumed that because all these properties may be supposed to hold for the series of instants in one's own mind, they must therefore be regarded as holding in respect of all instants. It would appear that the world in general has been making a somewhat similar blunder to that ascribed to Sir Boyle Roche.

My illustrious countryman is alleged to have said in a speech that, " not being a bird ", he " could not be in two places at once ".

People in general have assumed that an instant, like Sir Boyle Roche's bird, *could* be in two places at once, and it is this which I propose to call in question.

Thus while still regarding postulate 5_0 as holding for the

set of instants of which any one individual is directly conscious, or which any single particle of matter occupies, I propose to deny it for the universe in general and to substitute for it the following:

5. If A be any instant there is at least one other instant distinct from A, which is neither *before* nor *after* A.

If I be directly conscious of the instant A, then, an instant such as that here postulated will be one of which I am not directly conscious, but only indirectly apprehend, and which is, as I say, *elsewhere*. The other four postulates are, however, to be regarded as holding in general and not merely for a single individual or a single particle.

Since it is possible to distinguish an instant elsewhere in terms of *before* and *after*, it is unnecessary to have any separate concept of *space*, since the geometrical properties of space can be expressed in terms of these relations, although of course only through an elaborate logical analysis.

The kind of order which we thus ascribe to instants in general is what I have called "*conical order*", because it may be illustrated by means of ordinary geometrical cones; but it contains within itself the possibility of particular sets of instants having the simple linear order with which each of us is familiar.

This illustration is merely a mental aid to enable us to picture a certain set of abstract relations, and anything which we may introduce incidentally, and which cannot be described in terms of these relations is to be ignored.

Let us associate each point of space with a cone having the point as vertex, and let us further suppose that the axes of the cones are all parallel and their vertical angles all equal. In addition we shall suppose each cone to terminate at its vertex, the vertex itself being regarded as a point of the cone.

We shall call such a cone having its opening pointed in one direction (say upwards) an α cone and one with its opening pointed in the opposite direction, a β cone.

Thus corresponding to each point of space there is an α cone and a β cone having the vertex in common.

Now, by making a certain convention with respect to the use of the words *before* and *after*, it is possible to illustrate what we mean by " conical order ".

Let us therefore make the convention that if A_1 be any point of space and α_1 and β_1 be the corresponding α and β cones, then any point A_2 which is distinct from A_1 shall be said to be *after* A_1, provided it lies either on or inside the cone α_1, and shall be said to be *before* A_1, provided it lies either on or inside the cone β_1, but not otherwise.

Thus any point which is either identical with A_1 or which lies outside both the cones α_1 and β_1 will be neither *before* nor *after* the point A_1.

It will easily be seen that postulates 1, 2, 3, 4, and 5 hold generally when points are considered in place of instants; but that 5_0 only holds if we confine our attention to certain sets of points forming lines straight or curved.

Various other *before* and *after* relations of the points may be ascertained by a study of models of this kind, and we can then reverse the process and from certain propositions expressed in terms of *before* and *after* we can, by purely logical processes, build up a system of geometrical relations very closely analogous to those from which we set out, but in which nothing appears which cannot be expressed in terms of *before* and *after*.

We are able in this way, by taking the *before* and *after* relations as something real, to define in terms of them things which I call α and β sub-sets, having most though not all the properties of the cones, and then, step by step, to define lines, planes, &c., and ultimately to build up a system of geometry equivalent to the analytical geometry of Minkowski.

The cones only supply three-dimensional models, whereas the analytical geometry of Minkowski is four-dimensional; but most of the necessary postulates can be represented in three dimensions, and, in fact, there are only two which cannot.

One of these introduces an extra dimension, while the other limits the number of dimensions to four instead of three.

If, in such a model, we consider straight lines passing through a given point A_1, then we can see that these lines can be of three types. A line may either fall inside the cones α_1 and β_1; or it may form a generator of these cones; or it may fall outside them.

These three types correspond respectively to what I have previously called inertia lines, optical lines, and separation lines. In the case of the first two types, of any two distinct points, one is *after* the other.

In the case of the third type, no point is either *before* or *after* any other.

Again, if a plane be taken through A_1, it may be of any of three types according as it intersects the cones α_1 and β_1 in two straight lines; or is a tangent plane to the cones; or falls outside the cones.

These three types correspond respectively to what I called acceleration planes, optical planes, and separation planes.

Similarly there are three types of threefold, but to illustrate these we should require a four-dimensional model. All these entities may be defined in terms of *before* and *after* relations.

Equal lengths in the model do not, however, in general, represent equal lengths in our geometry; the latter being defined by a certain analysable similarity of *before* and *after* relations.

We are finally able to introduce co-ordinates, and then the system is seen to be equivalent to that of Minkowski.

One of these co-ordinates is measured along an inertia line and represents what clocks purport to measure; while the other three co-ordinates are measured along separation lines, and these represent what we call spacial distances.

Since, however, the whole theory has been built up in terms of *before* and *after*, we appear to have absorbed the theory of space into a theory of time, in which the instants have a conical order instead of a purely linear one, such as is generally assumed.

According to this theory an instant for the universe in

general requires four co-ordinates for its identification, and not merely one as is ordinarily supposed.

If the four co-ordinates axes are all "*normal*" to one another (normality being also defined in terms of *before* and *after*), then one and only one of them can be an inertia line, so that "local time" so-called is merely the value of this particular co-ordinate.

If we change to another normal co-ordinate system whose inertia axis is not parallel to that of the former, we have one which is appropriate to a material system which is moving uniformly with respect to that of the first, and we have a different "local time".

An inertia line is the time path of an unaccelerated particle; but, since any inertia line is exactly on a par with any other one, we can assign no meaning to a particle being at absolute rest.

Thus instead of regarding one's self as, so to speak, swimming along in an ocean of space, one is rather to think of one's self as somehow pursuing a path in a four-dimensional ocean of time, whose elements, taken as a whole, have a conical order, which is manifested to us in the form of spacial relations.

Other persons and other physical objects pursue different paths through this same ocean of time, and any one such path of a person or a particle is of such a character that the instants of which it is composed follow *after* one another.

Theory of a "Block Universe"

This view of the fundamental temporal character of space has an important bearing on the question of what Professor William James called a "*block universe*", and thence on the general idea of evolution as something real.

Most writers on relativity treat time as if it were a fourth dimension of space, an attitude which tends to favour the "block universe" idea.

When, instead, we regard time relations as fundamental, things appear in a very different light and the idea does not commend itself so strongly.

The asymmetrical character of the *before* and *after* relations, which forms the basis of the system of geometry which we have briefly described, finds no real counterpart in our ordinary spacial ideas.

It is true that we made use of a spacial model involving cones to enable us to represent graphically various postulates employed, but this was only done by means of an arbitrary convention as to what should represent *after* and what represent *before*.

This convention might have been reversed without affecting the usefulness of the representation; but by no stretch of imagination can one reverse the time relations of *before* and *after* which one perceives directly in one's mind.

Wherein, then, consists the essential peculiarity of these time relations which gives them their asymmetrical character?

One thing seems clear: if I at the instant A can produce any effect, however slight, at a distinct instant B, then this is *sufficient* to imply that B is *after* A.

A present action of mine may produce some effect tomorrow, but nothing which I may do now can have any effect on what occurred yesterday.

It appears to me that we have here got the essential feature of what we mean when we use the word *after*, and my suggestion is that the abstract power of a person or living being at the instant A to produce an effect at a distinct instant B is not merely a *sufficient* but also a *necessary* condition that B should be *after* A.

If, however, a person at the instant A cannot produce an effect at the instant B, it does not follow that B is *before* A. In order for this to be the case, it would be necessary that a person at B could produce an effect at A, since *before* and *after* are converse relations.

The significance of an instant A being neither *before* nor *after* a distinct instant B would then be that a person at A could produce no effect at B, and a person at B could produce no effect at A.

This *possibility* of producing an effect requires further

consideration, but I propose first to consider the physical circumstances under which one instant is neither *before* nor *after* another.

Now it is to be noted that, from the standpoint of pure mathematics, all that is presupposed in the system of geometry which we have considered is that there should be a set of elements which are related in a certain way which can be analysed in terms of a certain asymmetrical relation.

In endeavouring to apply this, we identify an element with an instant, and the asymmetrical relation with the physical relation of *after*.

The suitability or otherwise of the abstract geometry to describe actual time and space relations depends upon the accuracy with which the various postulates can be made to correspond with various physical facts.

Now it appears that a very close, though perhaps not an exact correspondence of this sort can be established by means of the properties of light.

If P and Q be two separate and distinct particles, and if a flash of light be sent out from P at the instant A directly to Q, so as to reach it at the instant B, then according to our interpretation of *after*, B must be *after* A.

Now there are strong physical grounds for believing that, at any rate in the absence of appreciable quantities of matter, light gives us a criterion which enables us to say that B is the *first instant at Q* which is *after* A, and that A is the *last instant at P* which is *before* B.

If this be so, and the light flash be reflected directly back to P so as to arrive there at the instant C, then any instant at P which is *after* A and *before* C is neither *before* nor *after* B.

Thus in Fizeau's experiment, any instant at the sending apparatus which was *after* the departure of a flash of light and *before* its return would be neither *before* nor *after* the instant of reflection at the distant mirror.

Einstein's " generalized relativity " suggests that the analytical geometry of Minkowski, with these optical interpre-

tations of its postulates, gives only an approximate although, under ordinary circumstances, a very closely approximate representation of time and space relationships; but it does not follow that with some slightly different interpretation it may not be exact.

In any case Einstein takes the measurement of intervals as fundamental in his generalized theory, and we have seen that this is not a suitable fundamental basis even for the simplest case of that theory—the geometry of Minkowski.

I think, therefore, that there can be little doubt that ideas of *before* and *after*, which enable us to define equality of intervals in Minkowski's theory (for cases in which equality of intervals has any meaning at all), and which certainly have some physical significance, will prove also to be the proper foundation for any generalization of that theory (such as that suggested by Einstein) which may be found necessary.[1]

This brings us back to the question of the physical meaning of *after* and its bearing upon the idea of a "block universe". If the universe were of a block nature it might be compared to a cinematograph film which was being gradually displayed before us, but which had been taken once and for all and could not be changed. The course of evolution would then have been settled through all eternity in a manner analogous to that in which the sequence of pictures in the cinematograph film was settled when the photographs were taken.

But are there really any grounds for thinking that the universe is of this nature?

If time and space may be analysed in terms of *before* and *after* relations and if *after* has the significance which we decided that it had, then it would seem that, so far from having grounds for a belief in a block universe, we have actually grounds for holding an opposite view.

[1] One method by which this might be done is suggested in the appendix to *The Absolute Relations of Time and Space*. This may or may not be the proper mode of procedure, but in any case it seems to give further justification for the opinion here expressed.

A Logical Difficulty Considered

This view of *after*, however, requires closer examination from a logical standpoint, although I believe that the majority of people would find the idea sufficiently clear for all practical purposes.

I must, however, make some attempt to meet the possible objections of logicians, who would probably refer to the " laws of thought ", and say of an event at some future instant that it must either occur or not occur. I do not propose to deny this, but I shall consider first the nature of a proposition, and try to make clear a distinction between what I shall call a *disjunctive proposition* and a *disjunction of propositions.*

Russell says that a proposition " is anything that is true or that is false ", and I propose to use the word proposition in this sense. Propositions may be of any degree of complexity, being built up from simple propositions in various ways.

Consider now, for example, the proposition: *I was in London last week or I was not in London last week.* This is a disjunction of two propositions: " I was in London last week " and " I was not in London last week ".

One of these propositions is true and the other is false, and, as a matter of fact, at the time I write, the second is the true one.

Let us, however, consider the proposition: *I shall be in London next week or I shall not be in London next week.* Although this appears to be so similar to the proposition first considered, there is a remarkable difference between them.

Though the latter proposition is true taken as a whole, yet neither one of its two components can be said to be either definitely true or definitely false.

No doubt one of them will *come true*, but as to which one it will be we can have no absolute certainty and can only " wait and see ".

The separate components in this case do not appear to satisfy our definition of a proposition; but the whole thing is

what I shall call a *disjunctive proposition* as distinguished from a disjunction of propositions.[1]

My suggestion then, which I put forth tentatively, amounts to this: that when the logical " law of excluded middle " refers to the occurrence of events, then, when the events are past, it is a disjunction of propositions, but, when the events are not past, it is a disjunctive proposition, except possibly when they are *at* the instant of assertion.

Thus the set of propositions which may be truly asserted at any instant is dependent upon every event which has happened *before* that instant, and the set would have been different if we suppose any one of these had not occurred.

Thus, in this sense, the occurrence or non-occurrence of any event at an instant A has some effect however slight at any instant which is *after* A.

Predictions as to future events are made on the assumption that certain observed uniformities will persist in the future.

Such assumptions are more or less liable to be falsified by actual events, particularly when we are dealing with living things.

In the case of these, predictions may be made which have a certain degree of probability based upon the habits of the living things; but these habits might change at any time and the prediction be falsified.

In the case of so-called dead matter, predictions may be made with much greater certainty; but one has no absolute

[1] The distinction which I wish to make may perhaps be made clearer by the following mathematical analogy:

Let x, m, and n be numbers which are restricted to be positive, and let

$$(x - m)^2 - n^2 = 0.$$

Then we must have

$$x = m + n,$$

or $$x = m - n.$$

If, however, m is less than n, one of these alternatives is excluded by the condition that the numbers are positive, and we can then definitely assert that $x = m + n$.

If, on the other hand, m is greater than n, both possibilities are open, and we cannot definitely assert either that $x = m + n$, or that $x = m - n$, but can only truly assert the disjunctive: $x = m + n$, or $x = m - n$.

guarantee that some of our so-called " laws " of dead matter are anything more than very confirmed habits which may also be broken.

Something of this sort may actually occur when so-called dead matter is absorbed into a living organism.

It thus appears that there is no incompatibility between the views which we have here expressed as to the nature of time and space on the one hand, and the view of evolution as being a real development on the other.

The actual conditions and course of such development I leave to the consideration of those who have made them a special study.

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CHAPTER XII

Philosophy

Science and Philosophy

A student of philosophy who contributes to a volume of essays on evolution may reasonably feel apprehensive that his particular contribution, coming at the end of a series of utterances by representatives of the physical and natural sciences, may have the effect of a cold douche after a warm bath. The earlier essays will naturally be mainly constructive and presumably enthusiastic in tone; the philosopher is bound to be critical, and possibly the tone of what he has to say may be found a little chilling. Each representative of the sciences has his story to tell of the advances achieved and still to be achieved in his own special province by the application of the evolutionary idea; the chief business of the philosopher is to utter a warning against the entertainment of unwarranted expectations. Or, to speak metaphorically, the idea of evolution may be likened to a key which has been found to fit a great many different locks; the function of the philosopher is to caution its possessor against assuming that it will prove to be a *passe-partout*. The difference in tone, however, arises quite inevitably from the difference of standpoint between philosophy and the special sciences. It is the proper task of each of these sciences to make all the use it can of every promising idea for the solution of its own special problems; to philosophy falls the less gracious task of considering the implications of the idea itself and the possible limitations those implications impose on its application. This work of criticism, though it may

be repellent to an ardent mind, is none the less unavoidable; if it makes no direct contribution to the enlargement of our knowledge, it clarifies our thought. If it opens no new vistas, it serves at any rate to prevent the waste of energy and the disappointment attendant on mistaken attempts to force a path for the intellect through an impenetrable jungle. Nothing is commoner in the history of science than the persistence of mankind in the determination to make a conception which has proved fertile in some fields of application into a principle of unrestricted applicability, and there is no error which avenges itself more mercilessly on those who commit it. Hence it is fitting that a series of studies of the triumphs achieved by the idea of evolution should be closed by a sober consideration of the question whether there are not some triumphs which the nature of the idea itself necessarily precludes. It may be natural to suppose that a theory which has already explained much and confidently promises to explain more, will, sooner or later, explain everything. Yet it is certain, if we will reflect, that no theory whatsoever can possibly provide a universal explanation of everything; this is why, though there are and ought to be evolutionary sciences, there can really be no such thing as an evolutionary philosophy. The object of the following pages is to show a little more in detail why this must be so by indicating certain general restrictions, inherent in the very notion of an "evolution", outside which no evolutionary conception can be made to work.

The Principle of "Analogy"

We may perhaps best prepare the way for our argument by beginning with the enunciation of an important principle of method which all that is to follow will develop further, and then illustrating the principle briefly from the history of the attempts which have been made to use the notion of evolution as the foundation of a complete philosophical interpretation of the world. And first as to the general principle of method.

Evolutionary ways of thinking have long ago made their

way into the whole field of the sciences. We talk not only of the evolution of organisms on the earth, but also of the evolution of the solar system or the evolution of the chemist's "elements";[1] we are at any rate in view of the formation of a theory of the evolution even of the "prime atom" of the physicist. Vast speculations are formed, and a whole literature written, dealing with the evolution of art, morals, religion, government, the whole of the varied institutions of the communal life of human society. And we find it quite natural that this should be so. We take it as a matter of course that as the biologist studies the evolution of a typical plant or animal, so the economist should study the evolution of the industrial system, the musician the evolution of the symphony, and the liturgiologist the evolution of the Canon of the Mass. It is an easy and natural step from this employment of the same word "evolution" in all these contexts to the unconscious assumption that in all three cases we are speaking of something which is identical. We may thus be led, almost before we know it, to take it for granted that all these "evolutions" can be alike described by one common "evolution-formula", and even that they all form a series of stages in one universal process of evolution. But the facts from which we started do not of themselves afford any justification for either assumption.

General Character of evolutionary Processes

On the face of it the processes we have mentioned are alike in one very important respect. They are all processes which culminate in the development of something with a relatively definite and stable character out of less definitely characterized and less stable beginnings. And again the thing developed is usually more complex than the beginnings to which we can trace it back. The structure of the human organism is much more complex than that of creatures whom we have reason to regard as our very remote progenitors; the differences between ourselves and our nearest existing animal congeners are much more distinctly marked than those we believe to have

[1] But see Prof. Soddy's remark on p. 401.

been present between our very remote ancestors and their near congeners; the stability with which we transmit our own peculiarities to our offspring contrasts with the much more considerable variability we have to ascribe to the organisms of those distant times. In the same way, to recur to our example, the official liturgy of one of the great Churches is a much more complex thing than the early models of congregational worship which preceded it in the history of Christianity; the divergencies by which an " Eastern " and a " Western " liturgy are distinguished from one another are more marked than the differences of earlier days between the extemporary prayers of different presiding " presbyters ", and the distinctions, once fixed, are perpetuated in a much more rigid form. Or again, if we compare the organization of industry to-day with the conditions of a century and a half ago, we meet with the same results. The specialization of function has been carried to a much higher pitch of complexity, the distinctions between different groups of workers have become much more accentuated, they are reproduced in successive generations with much greater fixity. At the earlier date, it was a comparatively easy business for a man who had lost the particular employment on which he had been engaged to find a place in some other where he could acquit himself equally, or about equally, well; in our own time one chief source of economic trouble is that the man who has lost one very special kind of work can commonly find no employment in any other, and would be of little use if he could.

Analogy not Identity

But we have to be carefully on our guard in all departments of thought against the insidious tendency to suppose that resemblances of this kind amount to an identity. What they establish is not identity, but analogy. In some respects the characteristics of development, physical, physiological, mental, social, present striking formal similarities. This does not, of itself, give us the right to suppose that the processes are simply identical or that they could all be equally well described by one

and the same general formula. It may equally be the case that there are many evolutionary processes, each with its own appropriate formula, but no single process with a single universally applicable formula. There may be not one " law of evolution " but a plurality of " laws of evolution " exhibiting certain broad analogies. If that should be the case, the attempt to make a single formula cover the whole field of development would compel us to choose a formula so vague that it tells us nothing in particular about any process of development, on pain of stating what is false the moment we try to give our " law " any precision. A simple illustration from another sphere may throw light on the gravity of this danger. There is a close formal analogy between the relations of the points on a straight line and those of the successive moments of time, an analogy which is exemplified whenever we represent a lapse of time graphically by a length, as we are constantly doing. But if we forget that the analogy is no more than an analogy and that a point and a moment are, after all, different things, we fall at once into danger of error. We may argue, for example, that since the straight line may be traversed in either direction, the order of succession in time is equally reversible, and thus come, like so many of the ancients, to believe in a future which will resuscitate the past.[1] But the belief directly contradicts one of the best-known principles of physics, the " principle of Carnot " or second law of thermodynamics. When a man has walked from A to B, it is a simple enough matter for him to turn round and walk back again from B to A. But the " downgrade tendency of energy " makes it impossible for Nature to retrace her steps in this fashion. All her great " periodic " or " cyclical " movements themselves are affected by irregularities, and you cannot, with the ancients, assume that there is some one

[1] For instance, it might be assumed that, if the molecules of a given gas at a given moment t have certain positions and velocities relative to one another, there will, after a definite interval of time, be another moment t_{11}, when the same particles will once more have precisely the same relative positions and velocities. The same thing will happen again, after a second interval of the same magnitude as the first, at another moment, t_{21}, and so on endlessly. And the same for the whole material world.

supreme " periodic " movement of Nature as a whole in which these irregularities are all cancelled out, without denying the " principle of Carnot ", one of the foundation-stones of our whole physical science. Gross as the error of the ancients was, it not only haunted the minds of serious thinkers for centuries, but, as we know, was revived in our own days by Nietzsche and given out by him as his supreme contribution to the wisdom of the ages. The example may well make us cautious in mistaking what may be no more than a formal analogy for absolute identity.

"Emergence" of the Moral

Still less does the formal analogy between various processes of development, purely physical, physiological, moral, justify us in assuming without further ado that all these processes form a single continuous history. In one sense, a rather superficial one, no doubt they might be said to do so. No one doubts that our solar system and our own globe had passed through many various stages of development before the appearance of the simplest organism to which we can trace back our own genealogy, or that the development of living species was going on on our planet in ages long anterior to the presence there of beings with even the rudiments of any " morality ". If all that we mean by saying that the growth of human civilization, the " evolution of species ", and the formation of the solar system itself form a continuous history is that the second-named process has come after the third and the first after the second in point of time, and that there have been no empty gaps in all this time, the statement is true enough, though a trifle obvious. But it does not follow that there have been no " new starts " anywhere throughout this period. It is clearly quite compatible with mere unbrokenness of the temporal sequence to suppose that the development may have exhibited a " new start " more than once. It might be, for instance, that so long as we are dealing with developments within the range of the inorganic, or again within the range of the merely organic but not conscious, or finally, within the range of the conscious but non-

intelligent, we can indicate precisely the connection of each later stage in the development with antecedent changes, accounting for the character of that which appears later completely by the character of what has gone before, but that the first appearance of life, or consciousness, or intelligence, as the case may be, presents us with something definitely *new*, something with a character not fully explicable by reference to anything in the character of what has preceded. If this proves to be so, in the cases mentioned or in others which might be mentioned, each such " emergence " of the genuinely *new* would create a gap in " evolutionary history " which we are unable to bridge. We should have to think of the process of development as taking a fresh departure after each of these gaps. We should have to say, for example, that we can trace a line of development in the inorganic world, and again another line of development in the world of living organisms, and that the " evolution-formulæ " of the two developments exhibit certain striking analogies, but that we can trace no development from the inorganic to the organic and consequently construct no formula which will cover the transition. Then it would follow that we could write histories of the several " evolutions ", e.g. of the chemical elements and their compounds, of organisms, of conscious beings, of mankind, but not a history of one single all-embracing " evolution " like that figured by the design on the cover of Mr. Herbert Spencer's volumes, where we see the crystal at the bottom of the drawing and the butterfly at the top. Whether what we have suggested as the possibility is the actual fact or not can, of course, only be determined by thorough and painstaking exploration of the whole range of the objects of human knowledge and precise determination of the formal characteristics of inorganic things, living creatures, conscious creatures, intelligent and moral creatures respectively. We have no right to exclude such a possibility from the outset without examination on the alleged ground that processes which have succeeded one another continuously in time must also form a single continuous development with a single formula. The assumption may be as mistaken as that which used to be

made by mathematicians who took it for granted that a " continuous " curve must have a tangent at every point. It is an initial possibility to be reckoned with that the course of development may be for the most part gradual and uniform, and yet may involve startling and catastrophic jumps at critical points.[1]

Darwin's Hypothesis Scientific, not Philosophical

Next a few words on the history of evolutionary hypotheses in *philosophy* before the great stimulus given to them by the biological work of Darwin and his contemporaries. The difference between a scientific and a philosophical use of the idea of evolution, a difference which it is of the first importance to clear thinking not to obliterate, may be illustrated by the contrast between the work of Darwin and the work of Herbert Spencer. The thought of Darwin, like the problem upon which it was directed, is strictly scientific, not philosophical. The problem he set himself to solve is one of limited and definite scope, that of the method by which a new species of plant or mind is brought into being and established as a permanent " variety ". The answer to such a question has to be based on the evidence of particular facts, considered independently of any pre-conceptions about the ultimate nature of the system of reality as a whole, and if the ascertainable facts point unambiguously to a definite answer, the answer has a right to be accepted which is unaffected by differences of opinion about the character of ultimate reality. It would be as absurd to call Darwin's particular theory of the factors which have led to the origination of new species into question on grounds of metaphysics as to urge metaphysical objections to a theory of the authorship of the *Letters of Junius* or the date of the builders of Stonehenge. Again, the definiteness of the question

[1] That such catastrophic "jumps" can occur in Nature in certain critical conditions is actually maintained by the advocates of the recent " quantum " theory. According to this theory, an electron which is swinging round a nucleus in a definite orbit and in a perfectly uniform manner may suffer a sudden "jump" from that orbit to another, emit a quantum of energy, and then pursue its new orbit, once more with complete uniformity.

Darwin set himself to solve gave a similar clear definition to his proposed answer. He not merely told us that the great variety of existing species must be considered as developed out of a much less considerable number, perhaps from a single original species, but he specified the exact factors by which he took the result to have been produced and the method of their operation. His theory has thus one indispensable characteristic of all genuinely scientific theories, it permits of confirmation or refutation by an appeal to empirically ascertained facts. The all-important question for the critic of Darwin is not what are his implied assumptions about ultimate reality (in fact he makes none), but whether further research into the specific facts of botany and zoology bears out his view that the variations from type which start a new species are produced by the gradual accumulation in successive generations of insensible differences, or whether these " mutations " are sudden and considerable. This is an issue to be determined not by a metaphysician's interpretation of the world at large, but by minute attention to the special experiences of the experimental botanist or breeder.

"Darwinism" a specifically Biological Theory

Similarly the field of the hypothesis is a strictly delimited one. In propounding a theory, right or wrong, of the gradual production of new vegetable and animal species by the slow accumulation, under specified influences, of minute variations from type, Darwin leaves it a perfectly open question whether other existing differences, like those between the chemical elements, have also been gradually developed, and if so, whether there is any special analogy between the process of development in this case and in that which he has chosen for investigation. The " Darwinian hypothesis " is one which can be accepted wholly " without prejudice " to hypotheses in other sciences than Darwin's own.

Spencer's Problem Philosophical, not Scientific

Spencer's attitude towards his problem is in all these

respects as unlike Darwin's as it well could be. To begin with, the problem itself is not in any way restricted or delimited. *His* doctrine of evolution is not intended to explain the precise process by which any particular part or feature of the manifold world we know has come to be what it is. It is an attempt to say once and for all how the whole of the world has come to be the world it is. Everything, according to the "synthetic philosophy", must have been "evolved" out of something simpler. (In the end, to be sure, this assumption ought to lead to the conclusion that everything has been developed out of an original characterless nothing; Mr. Spencer naturally did not push the argument quite so far, but was content to stop short with an original gaseous nebula as simple and featureless enough for his purpose.) Now this speculation, just because it is not restricted to any special field, is manifestly a "metaphysical" speculation about the nature of ultimate reality. (Formally, it is true, Spencer maintained that ultimate reality is unknowable. But his whole philosophy is built on the assumption that we know at any rate one very important thing about it. We know that the law of its being is to become steadily more and more complex, and consequently, on Spencer's assumption that the "homogeneous" is "unstable", more stable and determinate, as time goes on.) The famous evolution-formula according to which development is universally from an "indefinite unstable homogeneity" to a "definite stable heterogeneity" then, just because it is meant to apply to everything, really tells us nothing in particular about the actual development of anything. Its author often shows a curious ingenuity in bringing the actual known or supposed facts about the course of specific historical developments under his general formula, but it is fairly clear that equal ingenuity could as readily do the same thing for an assumed special development in the very reverse order from that known (or believed by Spencer) to be the historical one. And again the theory does not conform to the condition that it should be capable of definite confirmation or refutation by confrontation with specific facts. It is true, as has been remarked by the critics of

Spencer, that our experience seems to be very definitely contradicted by the assumption that the homogeneous is unstable and the heterogeneous stable. But I take it that Spencer might have replied that we have no experience of the behaviour of a " homogeneous " which has not a foreign and " heterogeneous " environment interacting with it, and are therefore not in a position to say what would happen to a *universe* which happened to be perfectly homogeneous. It might be possible to argue that if the " homogeneities " we know seem to be relatively stable, that is precisely because in becoming homogeneous they have definitely adjusted " inner relations " to " outer relations ", and that this adjustment had not been achieved by the " unknowable " in the supposed initial state when it was *all* " homogeneous " and had no " outer relations " at all.

We may, then, distinguish a properly scientific from a " philosophical " use of the notion of " evolution ". It is science, good or bad as the case may be, which we are elaborating when we propound a theory of the development of something specific and definite, under precisely statable influences, from something else specific and definite; when we lay it down as a principle that *whatever* at any time is *must* have been " evolved " from some earlier and different condition, or assume that there is one single all-embracing " evolution of the universe " and speculate about the law of this process, we are leaving science for what, as will be argued directly, is metaphysics and bad metaphysics. Most of these numerous persons who confuse these two very different attitudes of mind, no doubt, make the transition from the scientific to the metaphysical way of thinking about evolution unconsciously, and their unconsciousness that they are making it only adds to its dangers. The most obvious, perhaps the most important, service the metaphysician can render to the sciences is to warn their representatives against the errors into which we are all liable to be betrayed by acquiescence in metaphysical presuppositions of which we are normally unaware, the " metaphysics of everyday life ".

Evolutionary Speculations of the Greeks partly Scientific, partly Philosophical

Both the scientific and the philosophical employment of the notion of evolution make their appearance in the very first age of nascent European thought among the remarkable men whom we conveniently, if not very accurately, speak of as the "pre-Socratic" Greek "philosophers". The problem which these thinkers began by raising, "what is the original *stuff* of which everything around us is made?", is itself at once half scientific and half philosophical. It is half scientific, since its solution demands some kind of answer to the question by what specific and determinate process specific groups of bodies, with well-marked distinctions between them, have arisen; it is half philosophical, since it had not yet occurred to anyone that there can be things, such as, for example, our own minds, which are not bodies with some specific physical characters, and thus the question how the various kinds of bodies have been originated and the question how *everything* has come to be what it is, are not yet discriminated. Hence it is not surprising that we find side by side in the earliest Greek thought anticipations of quite modern theories about the origination of "species" in biology and anticipations of Mr. Spencer's universal evolution-formula.

Anaximander

Both are found, for example, in the reports we possess of the ideas of Anaximander of Miletus (*c.* 610–540 B.C.), the first Greek thinker who is much more than a name to us. Face to face with the question how a "world" or, as we should say, a "stellar system" comes to be, Anaximander rejects the view already put forward by his predecessor Thales, that "water" is the stuff of which everything is made. The stuff of things, he says, cannot be any of the obvious forms of body perceptible to our senses. If it were, so he presumably thought, we could never explain how all the other forms of

body came to be there. If all things were really water, would they not all be "moist"? Where does the "dry" come from? Would they not, again, all be "cold", and how, then, are we to account for the existence of the "hot"? Consequently Anaximander says that the primary stuff, of which all perceptible bodies are passing phases, must be something of which you can say no more than that it is a "boundless" something; the various things our senses perceive are "sifted out" from this "boundless", enjoy a passing existence, and then are resolved back into the "boundless" again by a movement of which we can say little more than that it is "eternal", has always been, and always will be, going on. Vague as the language is, the thought is precisely that of the Spencerian formula; Spencer's "homogeneous" answers precisely to the "boundless", and his alternating rhythm of "integration" and "differentiation" is just the "eternal motion" of Anaximander. Side by side with this anticipation of Spencer, Anaximander provides us with a still more striking anticipation, not only of modern theories of the evolution of living organisms, but of the kind of reasoning by which those theories are suggested and supported. In his account of the origin of mankind we have the first formulation of the notion of a progressive adaptation of the organism to its environment, and the earliest of many appeals to the long-protracted helplessness of the human infant as evidence. Mankind, he said, could never have survived if men, or their ancestors, had originally been what they are now, for the first young generation must have perished in its infancy. Men, therefore, must be descendants of beings with different physiological habits and a different habitat, and Anaximander was led from knowledge of the life of certain kinds of sharks to the conclusion that our ancestor was a species of fish whose young were accustomed to retreat into the parental organism in danger. These originally aquatic creatures in course of time took to living on dry land, adapted themselves to their new environment, changed their habits, and modified their physique, and thus the human species as we know it came into being.

Empedocles

Equally noteworthy, as an anticipation of ideas familiar to ourselves, is the account of the origin of existing species given by the poet, religious enthusiast, and physiologist Empedocles (*c.* 490–430 B.C.), a century after Anaximander. According to Empedocles, animals and all other things are temporary combinations of four ultimate kinds of " stuff ", the traditional four " elements ", as they came to be called in later days. The formation and destruction of these combinations is due to the alternate prevalence in the universe of two antithetic principles —forces, we should call them, but Empedocles still thinks of them naïvely as " bodies " of some kind—" love " and " strife ". " Love " is a principle of attraction between unlike " elements ", " strife " the antithetic principle of repulsion. At the moments when " love " is completely predominant in the universe all the " elements " are brought into one compact conglomerate: when " strife " is completely predominant, the " elements " are wholly disgregated from one another and form a succession of homogeneous layers or shells. At neither of these times is the existence of living organisms possible. But they can arise and perish again in either of the intervals between these extreme states of aggregation and disgregation, and the process of formation will take one of two reverse directions according as it falls in the time during which " love " is getting the upper hand over " strife " or " strife " prevailing against " love ". From a chance remark of Aristotle we learn that Empedocles supposed himself to be living in the latter of these periods, that in which the universe is passing from a state of complete aggregation to a state of complete disgregation of the " elements ". This remark gives us the clue to the interpretation of the fragments of the cosmological and physiological poem of Empedocles which deal with the origination of species in our own period of world-history. They are originated as " strife " gradually breaks up the single conglomerate, previously formed by " love ", into its constituent " elements ". Accordingly, Empedocles held that in the " evolution " to

which we belong, the earliest organisms were ill-constructed composites uniting in themselves characters which are now found separately specialized in several species, " oxen with the heads of men ", and the like. Most of these early products of evolution perished for want of proper " adaptation ". The better adapted were able to survive and leave offspring. Favourable adaptations arising at any stage of the process actually continued to persist. The first vertebrate, for example, was an animal which happened to break its back in trying to turn round; this new variation had now an advantage over its competitors whose backs were unbroken, and so the type has continued. Fantastic as some of the details of these explanations are, and mistaken as its starting-point is, we can see that it already presupposes not only the idea of adaptation to environment as a factor in evolution, but the more specifically Darwinian conception of the preservation of " chance " variations which prove advantageous, as well as the much disputed Lamarckian principle of the heritability of " acquired modifications ".

Non-evolutionary Character of Aristotelianism

As is well known, these evolutionary ideas thrown out in the earliest centuries of Greek science and philosophy failed to establish themselves firmly in the ancient world. The final legacy of Greek thought to succeeding ages was the conception of a world in which from all time (or, at any rate, as the Christian Middle Ages said, from the time of the Creation) the same " elements " have always existed and the same species maintained themselves unchanged. Commonly enough the acquiescence of centuries in this conception of a non-evolving world is supposed to be adequately explained by a reference to the dogmatic authority of Aristotle combined with that of Scripture as understood by the mediaeval Church. But the explanation is singularly incomplete. The authority of Scripture, which introduces the first man at the beginning of the Old Testament narrative and seems to imply that his appearance was due to a special act of creation of a unique kind, might

explain why the "descent of man" ceased for so long to be an object of inquiry, but does not explain sufficiently why the "six days of creation" should have been understood so literally as to exclude the thought of the gradual emergence of the rest of the living creatures. And the appeal to the authority of Aristotle leaves it unexplained why Aristotle himself turned his back on "evolutionary" ways of thinking. That he should have done so is in some ways remarkable. One would have thought that the conception of the successive development of more and more richly endowed and organized species would have been welcome to a philosopher whose most characteristic doctrine is that *all* processes are relative to the "end" or "completion" in which they culminate, and one who knew so well how to apply this conception to human history in dealing with the succession of phases through which the institutions and customs of human society have reached a climax in the civilized "State". Obviously we ought to ask why in his biology Aristotle was content with applying the notion of biological development to the growth of the individual. Why did he not extend it to the kind?

Hegel and Evolution

Precisely the same question is forced on us by the consideration of the first modern philosophies in which the notion of development again becomes predominant, the German "idealisms" of the opening of the nineteenth century which culminated in the doctrine of Hegel. Like Aristotle, Hegel is dominated by the thought that the more rudimentary can only be properly understood in the light of the more fully developed. Everything must be understood by reference to the "end" to which it tends. If we would know what the significance of religion is, we must read the different historical religions in the light of their relation to the perfect and final religion (Christianity as understood by Hegel); if we are aiming at an intelligent appreciation of human moral and social institutions, we must envisage them all as remoter or closer approximations to the perfect social system (which bears

a remarkable family likeness to that of Prussia in A.D. 1830). Philosophies, again, are to be regarded and evaluated as so many more or less stammering attempts to formulate the one *philosophia perennis* which has at last become fully articulate in Hegel himself. Above all, Hegel's *Logic* is a magnificent and audacious attempt to represent the whole series of conceptions by which thought tries to make its object completely intelligible, from the very emptiest and poorest, that of a mere " something " or "being", up to the richest and fullest, that of the Divine Spirit, as a serial development in which the successive members are so closely linked that you cannot take the initial step of thinking the first without being forced on in consistency to advance through the whole series in order until you reach the last. Yet Hegel is careful to insist on the point that the line of development of which he has so much to say is always one of logical order, not of order of succession in time. He regards it as a coarse misinterpretation of the whole conception to suppose that there is any intrinsic connection between higher perfection in the order of development and later appearance in the order of temporal succession. Indeed his thought seems to have been that you can hardly speak of an " order " in Nature at all; there is something wilful and capricious at the very root of Nature, where we find the more and the less perfect produced apparently in haphazard and casual juxtaposition on no discernible principle. It is just the contrast between this apparent casualness and the elaborate serial arrangement of the " categories " of logic which Hegel means by the " lapse into immediacy " he declares to be characteristic of " Nature ". Rationality is present and all-permeating in " Nature ", but present in masquerade disguise. The disguise characteristic of " Nature " would be gone if the order of " development " were also the order of temporal succession.

Reasons for this Attitude

Whatever our personal opinion of views like these may be, it is at least certain that neither Hegel nor Aristotle can be complacently dismissed as a mere fool. They are both serious

thinkers and thinkers of a high order; they may be capable of mistakes and very grave mistakes, but they are not readily to be charged with simple intellectual levity. Something at least may be learned from an attempt to understand why their attitude to what we now call " evolutionary " ideas is so unsympathetic. In making the attempt we shall once more find it important to distinguish between evolution as a scientific, and more particularly a biological, hypothesis and evolution as a metaphysical principle.

The reason why Aristotle, the most eminent biologist of the ancient world, rejected all theories of the gradual origination of species is not, I think, hard to discover, nor is it at all discreditable to his intelligence. It is the simple fact that, so far as Aristotle or any of his contemporaries could know, there was no evidence for the mutability of organic types. The speculations of an Anaximander or an Empedocles were dazzling, and as we can now see, they were just the daring kind of " anticipations of experience " which make advance possible. But down to the time of Aristotle these anticipations remained unconfirmed. Facts, so far as they were known, were definitely against the view that species are other than fixed constants in Nature; to treat them as anything else would have been to base the explanation of natural processes upon unverifiable hypotheses about a supposed prehistoric age in which natural conditions were of an unknown kind, and such mere appeals to the possibilities of the entirely unknown are in all ages rightly treated with suspicion by a science properly anxious to confine itself to regions where hypothesis can be kept under the control of ascertained fact.

The same consideration applies with an almost undiminished force to the case of Hegel and his contemporaries. What was needed to convert the brilliant suggestions of certain early Greek thinkers into " live " hypotheses with a claim to be regarded as genuine solutions of concrete scientific problems was the sort of evidence of formerly unsuspected facts disclosed first by the revelations of the very modern science of palæontology, and secondly by attentive study of the experi-

ences of the practical breeder of " fancy " plants and animals. Apart from this fresh knowledge of relevant facts, speculations about the " origin of species " would have remained to this day speculations " in the air ". With the accumulation of relevant knowledge about specific matter of fact (knowledge, that is, which permits us definitely to bring the hypothesis to the test), the establishment or rejection of any determinate solution of a properly restricted scientific problem becomes independent of all considerations of general metaphysics. It would be as reasonable to allow " philosophy " a voice in deciding whether there can be a general solution of an algebraical equation of a higher degree than the fourth as to permit her to intervene in the discussion of the line of descent of existing species and the factors which determine the origination or perpetuation of a " mutation ". In this field, the sciences which take cognizance of the relevant facts have a rightful autonomy.

Provisional Character of Science

Only we must remember that they exercise this autonomy subject to one obvious but important reservation. The reservation is that no confirmation of an hypothesis by fact can guarantee it once and for all against all modification in detail. The precise details of scientific theory are always open to modification by confrontation with facts yet to be ascertained, even when the confirmation by fact is complete in the present state of our knowledge of fact. This is why no science can ever reach, or ought ever to aim at reaching, finality in its hypothetical explanations. All our results are " provisional " and " tentative "; or, to put the same thing in more complimentary language, science is always " progressive ". So far as it can be said to achieve finality at all, it achieves it in its denials, not in its affirmations. Thus we may regard the work of Darwin as final on its negative side. It definitely negatives the conception of " kinds " as constants fixed once and for all. On the positive side, Darwin's, or any other, hypothesis about the precise factors which determine the origination of a " kind ", and their

relative importance, is always open to revision. It is inevitable, but unfortunate, that the positive suggestions of a great hypothesis (in Darwin's case, e.g., the importance attached to the "struggle" for existence as the primary factor in determining the course of evolution) should regularly tend to impress the popular imagination and to be regarded by the public at large as final, long after their provisional character has been fully recognized by the specialist student.

Evolution cannot be the Last Word of Philosophy

With "evolution" as a *philosophical* conception the case is different. It is abundantly clear, when we set ourselves to analyse the conception of development, that evolution cannot possibly be the last word of a philosophical interpretation of the world, and that we need to be constantly on our guard against the tendency to read into the notion much which it does not really contain. Philosophy, no doubt, needs to make use of the conception of evolution, but a philosophy *based* on that conception must necessarily end in illusion. We may consider some of the illusions created by the tendency to overestimate the philosophical significance of evolution as a principle of explanation.

Implications of Evolution

In the first place, we must consider what the manifest implications of the conception are. When we speak of anything as evolving we mean two things. It is changing its character, and it is changing its character in response to external conditions of some kind. The whole possibility of an evolutionary explanation depends on our ability to connect the series of changes in the thing which is "evolving" with definite external factors which determine the line of the evolution. All evolution thus presupposes the distinction between that which evolves and its "environment", and on interaction between the two. It is further implied that, though the "environment" itself need not be absolutely unchanging, it is at least relatively more stable than that which it "environs". But for this superior

relative stability we should not feel that we had in any way "explained" change by tracing it back to the presence of the "environment". To take a simple illustration. It is characteristic of man by contrast with his animal congeners that he does not passively wait for a disharmony between himself and his physical "environment" to be removed by adaptation of himself, in course of time, to the "necessities of the situation". If his environment and his felt wants are at variance, the civilized man sets to work not to change himself but to transform the "environment". People who have to live in a waterless region or in a marsh do not wait for the appearance, in the course of generations, of survivors who have become "adapted" to such a situation; they drain the marsh or irrigate the desert. Hence in writing the story of man's relations with physical nature, as we advance from man in a state of savagery to man in a state of intelligent civilization, the tale changes its character. At the outset we are roughly right in treating it as a tale of the modification of man by a relatively stationary environment. In its later stages it would be truer to speak of a modification of physical nature by man, possessed of relatively stable ideals. It is rather Australia which is being "evolved" by man than man who is being "evolved" by the Australian climate. The climate was once the environment determining the development of human society; to-day it is rather human society which plays the part of the environment under which the physical characteristics of Australia are being evolved, and we may look to see this reversal of parts become steadily more marked if civilized humanity does not destroy itself by its world-wars and class-conflicts.

Evolution (a) Presupposes "Environment" and "Environed", and their Interaction

The point on which I want chiefly to insist, however, is the simple fact of the duality and the interaction between the subject of evolution and its environment. When either factor is suppressed, you can have no evolution. If the subject be supposed suppressed, there is nothing to evolve; suppress the

environment and you are left with an " absolute becoming ", mere inexplicable change. It follows at once that we cannot intelligently think of the " physical universe " as " in evolution ", except on condition that we do not identify the " physical universe " with the totality of all that is. To talk of an " evolution " of all that is is to speak without meaning, since there can be no " environment " of the whole of what is. In fact we could not even talk of so much as change itself on the part of all that is without renouncing the principles on which all thinking is based. Philosophy and science alike are built on the assumption that when there is change, there is a reason for the change, and a reason for which we are entitled to ask. And the reason for a change can only be found in something not involved in that change. It follows that if there is such a thing as a process of change with a definite and discoverable law which embraces the *whole* of physical reality, the whole of physical reality must have a non-physical environment, and it must be the nature of this non-physical environment which determines the lines along which the physical, as a whole, is changing. And if this non-physical environment, or any part of it, is itself changing and changing in a definite way, the same considerations must in the end apply to it.

(b) Presupposes the " Eternal "

Evolution itself is only thinkable on condition that we think of it as conditioned by the existence of some reality or realities strictly unchanging and eternal. If by the " universe " we mean the totality of everything real, there can be no " evolution " of the universe, there can only be " evolutions " of part-constituents of it. We could only conceive of an evolution of the " universe " on the condition that we are using that word in an improper sense to mean something less than " all that is ". We might, as I said, conceive of " the whole of *physical* reality " as " evolving " as a whole, but only on the condition that we regard this so-called whole as a mere part, and not the most important part, of what is real. We should then have to face two further questions of the gravest philo-

sophical import into which I must not enter here. (*a*) Can we really speak of the eternal reality (or realities), implied as the unchanging background and source of change, and the changing realities as together forming a *whole* at all? (*b*) Is the physical, considered by itself, in any sense even a relative whole? Is it not rather in its very nature fragmentary and incomplete?

(c) Is always of some "Part" of the Real

To call attention to the mere existence of these two problems is in itself enough to show the rashness of constructing a philosophy on the assumption that an evolution-formula can be the last word about things. Here, if anywhere, Kant's warning against the "dialectical" illusion is in place. If we trace evolutions everywhere in nature and history, it is because in every case we are dealing with some fragment of the real which has a real environment outside itself and responds to the environment. To transfer our evolutionary modes of thinking to a whole assumed to have no environment is to suppress the condition which gives them all their meaning and fruitfulness. Here, then, is one necessary restriction on the employment of the notion of evolution. It can only be applied to that which has an environment other than, and relatively more stable than, itself, and is therefore not the whole of being but a fragment of it, and again only to that which is secondary, not to that which is ultimate. Even within these limits, it does not follow from the consideration that we can trace evolutions throughout each of several regions of existence taken severally, that they must collectively constitute one evolving system exhibiting one single law of evolution. To make this assumption would be like supposing with the ancients that all astronomical movements must form a single rhythm with a single period, because each of these separately considered has its periodic rhythm.

Modification not wholly determined by "Environment"

We may go on to note a second restriction. An evolution is a process in which the subject responds by answering modifica-

tion to modification of its environment. The nature of the answering modification is thus not wholly and completely determined by the environment and its modification; it depends also on the specific character of the subject of the evolution. The subject answers as it can to the change in the environment, and different subjects respond in different ways. The character of the subject of the evolution becomes more and more rich in stable and determinate features as the process advances, but it must have from the very first some definite character if there is to be any response to environment; we cannot intelligibly think of definite character as " evolved " out of a purely featureless plasticity. For the purely plastic and featureless would be only another name for just nothing at all, and no environment can be supposed to elicit a response from a bare nothing. To " call things from nothing " is the act not of an environment but of a creating God, and it is an act for which there can be no formula. Hence, again, it can at best be only a partial, not a complete, explanation of the characters of things to trace their evolution from something more primitive. Any formula of evolution must begin with subjects of evolution which have already *some* definite character; you cannot derive the existing characters of things simply from the response made by an initial nothing to its environment, (even if you were not equally committed to the task of deriving that environment too out of a still more ultimate nothing).

Spencer's Evolution Formula Empty

This consideration shows the utter vanity of a formula like Spencer's, if you once suppose the formula to mean what it says. If it means what it says, it undertakes to produce the whole variety of nature out of an original assumed complete " homogeneity ". But such a complete homogeneity is no more than a polite *alias* for nothing at all, a nothing where there is neither a subject of evolution nor an environment for it to respond to. And in point of fact Spencer does not even attempt to execute his own programme. He is content to start with a primordial gaseous nebula as a sufficient approximation to the

" homogeneous ". It has been pointed out by Professor James Ward that even so Spencer only gets a solar system out of his original nebula at the cost of denying the Conservation of Angular Momentum; but there is a still more serious defect in his procedure than this, and it occurs at the very outset. A nebula with a uniform temperature may be a much more " homogeneous " thing than any of those with which we are more familiar. But on closer inspection it may prove to be remarkably " heterogeneous " too. The uniformity of the temperature does not in the least imply an absolutely uniform condition of the ultimate constituents (the atoms or, if you like, the electrons) composing the nebula. This will be seen from a simple comparison of the relatively " homogeneous " out of which Spencer produces our stellar system with the similar " homogeneous " prophesied by so many physicists as its final state. The system, we are told, appears to be " running down " towards a condition in which its energy will have been finally dissipated into a form in which none of it is available for " work ". Space will then be permeated by a uniform low temperature; all differential motion will have ceased, and the sequence of changes we call the course of Nature will have come to an end. But when the physicists say this they do not mean that all atoms or electrons will be moving alike. On the contrary, the differences between the velocity of individual atoms are conceived as persisting undiminished in this dreary final state of the " universe ". The dead-level " homogeneity " is homogeneity between *aggregates*, the " temperature " of a volume of a gas being a condition of the aggregate, not of its individual elementary constituents. Hence Clerk Maxwell could imagine a restoration of the system to its former condition by the action of an assumed intelligent " demon " capable of dealing directly with the individual atoms of a gas of uniform temperature, and sorting out the swifter and the slower into two separate aggregates.

The moral of Clerk Maxwell's apologue of the sorting " demon " may be seen at once by transferring him from the end of a period of " evolution " to its beginning. It is just this,

that to get " work " out of your system at all, you must suppose it to start with the juxtaposition of aggregates of violently contrasted thermal condition. To put it roughly, there must be intensely " hot " bodies with intensely " cold " ones in their vicinity in order that there may be violent and rapid transference of " thermal energy " from the hotter to the colder; you begin thus not with " homogeneity " but with highly marked " heterogeneity ". You cannot get a long-continued history of manifold change and variety out of a beginning where there is no variety at all. Variety must be as original as uniformity.

Variety not fully explicable

This of itself is enough to show that the dream which, in different forms, has haunted the imagination of so many philosophical speculators, the dream of explaining away all the variety in the world as derivative, is a dream and nothing more. When we find variety existing we are driven by a sound scientific instinct to try, so far as we can, to " explain " it by exhibiting it as a consequence of some earlier state of things in which the particular form of variety under consideration was not as yet present. But the explanation can only be successful on condition that some other form of variety is presupposed as pre-existing. And hence there can be no final " evolutionary " explanation of being as a whole, any more than there can be a manufacture of manifold and different objects out of a " raw material " which has no character of its own and is thus pure nothing. Every evolution presupposes both a material and agencies acting on the material which are anterior to the evolution itself, and the process of accounting for these *praesupposita* as the results of a still earlier evolution cannot " go to infinity". Somewhere behind all evolutions and supplying all with "material" and "driving force" there must be the strictly eternal.

There are certain further cautions which must be carefully kept in mind if the use of evolutionary notions is not to mislead us dangerously. We may attempt a brief tabulation of some of these cautions.

"Explaining" and "Explaining Away"

(1) We need always to be on our guard against the insidious tendency to think that by "explaining" a thing we have "explained it away". When we have shown that something has been produced by a perhaps slow and imperceptible development, we must not suppose that we have shown the product to be any less real than the factors out of which it has been produced. Thus, suppose we have been successful in tracing back the ancestry of man to ancestors whom he has in common with the "anthropoids", or with the vertebrates, or even with a still wider range of living types, for example, "multi-cellular organisms". Our success does not in the least alter the fact that you and I are men and not mere "anthropoids" or "vertebrates" or "multi-cellular organisms". The differences between ourselves and our nearer or remoter relatives are just as real and significant as the fact of the common ancestry. As Butler wrote long ago, "everything is itself and not another thing", not, we may add by way of comment, its own remote ancestors.

"Origin" and "Value"

The ethical bearing of this consideration must never be forgotten. It not infrequently happens that some moral rule or custom of civilized mankind is speculatively derived from an original barbaric "taboo" which looks to be purely superstitious, and the inference then drawn that because the alleged origin of the civilized practice is foolish and irrational, the practice itself is equally senseless. But, apart from the question whether the alleged derivation has been sufficiently made out, it is in itself a fallacy to argue that what has arisen out of superstitious and irrational beginnings must be itself a superstition. The practice now existing, however it may have originated, has to be justified or condemned on its own merits, not on those of what is known or guessed to have been its far-away "origin". The question of origins is only relevant

to that of present value when no other evidence on this latter point is forthcoming. If a practice or institution pretty clearly had an irrational origin, then in the absence of any other reason to the contrary, the irrationality of the origin may be urged as a presumption that the derivative is also irrational. But this is no more than a presumption, like evidence produced in a law-court about a man's " antecedents ", and the presumption in both cases has no weight against direct evidence of the worth of a practice or the personal character of a man on his trial.

Reality of the Genuinely New

(2) We may give this reflection a wider scope. The most successful establishment of descent in the line of evolution is no proof that the product of evolution, when it appears, is not something genuinely *new*. We cannot infer that because C has been produced out of A and B, C, when produced, contains nothing which was not there before, is only A and B over again. When we have made as complete an enumeration as possible of the " factors " out of which a thing has been developed, it still remains true that the thing itself, once developed, may exhibit a character which was not present in all or any of these factors, and could not have been foretold on the strength of the fullest knowledge of the characters of the factors. As Mill said long ago, a man might know all the chemist has to tell him about the properties of mercury and those of oxygen, and yet be quite unable to foresee that the red oxide of mercury would be a coloured powder. What sort of thing would come of the mixing of the mercury and the oxygen had to be discovered by trying the experiment.

It is true that chemical knowledge has advanced greatly since Mill wrote that sentence, and that the more modern chemist has often been able to predict important properties of compounds before their actual production. But it remains true in principle that we have no guarantee that any new product of a development will not exhibit *some* characters of which its antecedents exhibited no sign, and these new characters may

be just those which are in every way the most important characters of the product. Development is entirely misconceived if we think of it as the mere reshuffling of pre-existent materials. This is why the more philosophical biologists of to-day, like Professor Lloyd Morgan, are found dwelling on the point that their doctrine is one of *emergent* evolution. Their point is that in the product of a development there is always something more than a mere rearrangement of characters already present in its sources, there is regularly something genuinely novel. Hence it follows that there may be specially well-marked critical points in a development where a particularly marked and important novelty makes its appearance for the first time.

We might, for example, conceive of life as making its appearance for the first time at a certain point in a process of development without having to account for this by assuming that there had really been an earlier undetected presence of the same character. We need not, for instance, postulate the conveyance of an already living germ to our planet by a meteorite, or something of that kind, to account for the dawn of life on the earth. We may believe that the living succeeded to the non-living without intervention of this kind. Yet life, when once it has appeared, may mark a turning-point in the process of development. That is, we might be able to find a formula which would accurately describe the process of development within the non-living world up to the point at which life made its appearance, and another which similarly describes the course of development of living organisms after this point; but, just because life is a startlingly new character which could not have been deduced from any knowledge of merely physical and chemical characters, we should be unable to make any formula cover the transition from the one stage in the history of our planet to the other. We might have a history of the development of chemical elements and compounds, and a history of the development of forms of life. But we could have no history of a gradual transition through intermediate stages from the lifeless, through the " not quite lifeless and yet not quite living " to the living. We might have to be content with

recording the bare fact of the supervention of the living on the lifeless.

An Application to Ethics

So the same view may be taken, for example, of the relation of man as a moral being to his congeners. It would be quite consistent with a belief in the biological continuity of organic types to hold that in the reflective intelligence which makes us capable of moral responsibility we are dealing with a character which is a novelty incapable of being " explained " in terms of any or all of the characters of the biological ancestors of the first intelligent creature. T. H. Green would thus be justified by an " emergent " type of evolutionary theory, in his contention, based on grounds independent of " evolution ", that we can write a history of morality in the sense of a history of the development of a higher out of a lower morality, but no history of the development of morality out of non-moral beginnings. For, if there really is the emergence of novelty anywhere in the course of a development, it follows, of course, that within the development itself, whenever a really significant novelty " emerges ", there is a solution of inner continuity. Since the new character cannot be analysed back into any combination of pre-existing characters, it must itself figure as a given initial datum in the study of any further development along the new line struck out by its " emergence ".

Importance of the "Background"

Something further, I take it, needs to be added to this mere recognition of the emergence of novelty as a feature of development. We cannot account for the genuinely new by reading its presence back into its pre-existing factors; if we could, there would be no real novelty in the case. On the other hand, it would be a violation of the very principle which justifies us in believing that explanation of anything is necessary or possible to suppose that there is *no* reason why the new character should make its appearance, that its " emergence " is simply uncaused. When A and B give rise to a C which is really some-

thing new, we thus seem to be confronted with a dilemma. The appearance of C is not accounted for by the character of the factors A and B, for C is neither A nor B, nor yet " A and B ", but C; on the other hand there must be *some* reason why just this combination (AB) and no other has given rise to the new C, and why the novelty has just the character C and not a different character. Some reason there must be, and yet we seem to have excluded the one relevant ground of explanation, the factors A and B. We only escape this dilemma by remembering that the conditions of every development include a great deal besides the constituent factors. " A and B giving rise to C " is not a complete and self-contained process. It is a part-event within the " wider event we call Nature ", not isolated from any of the other " part events ". A and B may be the only factors in C, but the process of the development has been open to countless influences, it is a moment in the whole life of the " universe " and its setting in this context is a relevant determinant of its course. Hence a " product of evolution " is only partially accounted for when we have succeeded in discovering its specific factors; its whole setting in the rest of the " universe " of facts must be regarded as conditioning its " emergence ", though we cannot say precisely in what way. Unless we bear this in mind, we are likely to find a difficulty in understanding how the really novel can be originated in the course of a development, and consequently to fall into the error of supposing that every product of evolution is simply its own antecedents reshuffled.

"Total Cause" and "Part Cause"

This consideration seems to give meaning and significance to a well-known formula of neo-Platonic and scholastic metaphysics, the saying that " whatever exists in the effect must have existed either formally or eminently in its cause ". The meaning of the phrase is that the characters of the effect must have been present in its cause either in the same way in which they are present in the effect (as, for example, when an animal is begotten by a parent of its own species) or else " in some

more excellent way ". (For example, a house is not built by a house or begotten by a house but built by an architect. In this case the plan, which in the finished house is embodied in an arrangement of unconscious stones, bricks, and beams, was said to have pre-existed in the builder's mind " in a more excellent way ", i.e. as a *conscious* intelligent design.) Now, if the really novel " emerges " as a result of development, this is plainly a case where we must not say that the character of the effect was to be found " formally " in any causal antecedents which we can isolate and name. Life, for example, will " emerge " from or supervene upon a development in which the earliest stages can be adequately described in the terminology of physics and chemistry. But it will not have been an actual character of the chemical products which, in our account of the line of development, preceded the appearance of the earliest living tissue. To understand its appearance we have, as we said, to remember that these products themselves were all along open to an infinity of influences which we cannot analyse, and it is just this consideration which makes it possible to believe in " emergent evolution " without denying the principle, fundamental to all " explanation ", that *e nihilo nihil fit*. If we were right in arguing that behind all evolutions there must be the eternal from which they all get their " driving force ", this will mean that the emergence of the new is possible, and yet it is also true that no cause can contribute to an effect what it has not to give. The full and ultimate cause of every effect in a process of evolution will have to be found not simply in the special characters of its recognizable antecedents but in the character of the eternal which is at the back of all development. And this must thus contain " in a more eminent manner " all that it bestows, and may contain much more, since we must not infer that what it has hitherto bestowed is all it can have to give. It is along these lines, though the development of the thought must not be attempted here, that we might set ourselves to show that there is no ultimate conflict between the conceptions of " creation " and of " evolution ", but that they rather complete and integrate one another.

"Evolution" and "Creation" Compatible

This may be specially illustrated by reference to a difficulty which has been too often overlooked by thinkers anxious to extend the conceptions proper to a theory of biological evolution into the sphere of the strictly spiritual. The attempt is often made to treat human personality itself as though it could be "inherited" from ancestors exactly in the same way as a physical peculiarity. Moralists like T. H. Green have steadily protested against this "naturalistic" way of thinking, but their protests, however sound, have inevitably had very little effect upon the evolutionary psychologists and anthropologists. Yet the difficulty can also be stated, as it has been stated by our greatest living[1] psychologist, who is also one of our greatest living philosophers, Professor James Ward, in a way which the evolutionist ought to find singularly pertinent. There is one important point at which the analogy between biological and psychological "heredity" breaks down. On the biological side there is continuity of an unmistakable kind between the parent organism or organisms and the organism of the offspring. What becomes the organism of the offspring has been at one stage in its history an integral constituent part of the parent organism or organisms. Its history can be traced back to a stage at which the subject of the evolution is actually a part of its own ancestry. On the psychical side this condition is wholly absent. My mind has never, at any stage of its development, been a part of the mind of a parent or parents. It is true that if my parents had never existed my mind would never have existed. It is also made sufficiently clear by the evidence of fact that mental peculiarities are in some sense "inherited". If the personality of my parents had been different, there is every reason to think that this would have made a difference to my own personality. Yet my personality is not, as a fact, continuous with those of my parents in the same sense in which my organism is continuous with theirs. We can understand the notion of a "continuity of germ-plasm"; to speak of a

[1] This sentence was written just before Dr. Ward's lamented death.

continuous " psychoplasm " would be to speak unintelligibly. Clearly this absence of analogy between the two cases sets a limit to the possibility of simply transferring biological formulæ and modes of thought to psychology. In psychology we must be content to say with Dr. Ward that what is " heritable " is not individual personality or character, but simply a " tendency " on the part of the new individual to develop along certain lines. In dealing with the *origination* of the fresh personality, we seem to have reached a point where it is inevitable that we should introduce into science itself that very notion of a new " creation " which we rightly exclude from the physical sciences because it would be superfluous there. The scholastic doctrine of the direct creation of each " rational soul " by God appears to embody a principle which psychology cannot afford to overlook. The appearance of a new psychical subject of experience is a fact which is and must remain inexplicable by any theory of development. But once there, the new subject has its special range of " tendencies " and " capabilities ", and these, out of which it has itself to make its character, are conditioned in various ways by its ancestry, the precise determination of these ways being a proper and fruitful field for empirical research.

Mental Characters, in what sense "Heritable"

There is actually a practical consequence of this distinction between the continuity on the side of the organism and the discontinuity on the side of the correlated mind. Unless we are on our guard, we are always in danger of expecting mental " heredity " to exhibit itself as unambiguously as physical. In popular thought, for example, it is readily assumed that given moral good or bad qualities or given specific capacities will " run " in families much as a physical peculiarity does. A family virtue or vice or a family " gift " or " accomplishment " is commonly thought to be the same sort of fixed character as a " family nose ". But these assumptions wholly neglect to take account of the superior plasticity of the " tendencies " which make up a man's mental " heredity ". When

we take this plasticity into account, we can readily see that we have no right at all to think of hereditary virtues and vices. A man may inherit with his physique a high degree or a low degree of sensibility to the pleasures of sex or of alcoholic drink, or a tendency to explosions of resentment; he does not inherit profligacy or drunkenness or "wrath". Whether a native sensibility to the attractions of sex or of alcohol will be the foundation of a moral virtue or of a vice depends on the attitude of a man through life to these tendencies. If a man, knowing that he has these proclivities, resolutely sets himself to master them instead of allowing them to master him, their very presence may be the secret explanation of a command over elementary appetites which is exceptionally complete. So it would be rash to assume that a man who is distinguished by gentleness and courtesy under provocation, and command of his "temper" generally, must have been born with a less irascible temperament than his neighbours. His habitual forbearance and patience may actually be the consequence of a prolonged and successful conflict with a naturally hot and overbearing "temper". This is why the popular assumption, that the man who is not a "sinner" has only escaped because he has never been subjected to the "temptations" which prove too strong for the "sinner", leads us so badly astray in our interpretations of character if we accept it uncritically. So again, we are not entitled to assume that capacity of *a specific kind* will regularly show itself in successive generations, nor to argue that "heredity" has been shown to be a superstition in psychology if this assumption is found to break down. Whether specialized capacity runs in families is a matter for investigation with reference to each of its forms, musical capacity, mathematical capacity, and the like. All we have a right to anticipate on general grounds is that the offspring of persons markedly above the average of ability in some respect should also prove to have superior ability of some kind. For example, it would be no proof that ability is not hereditary, to show that the descendants of great statesmen do not on the whole possess more political ability than other men or the sons of remarkably successful

men of business more commercial ability. What would have to be shown is that there is no discoverable tendency in either class to display superior ability of any kind.

Complexity and Stability Secondary

(3) At the beginning of this essay " evolution " was assumed to mean a process of " adaptation " to environment, and we said that, generally speaking, this process exhibits an advance in complexity and definiteness and an increasing stability in its successive products. It is important, however, to bear in mind that these last two characteristics are, after all, secondary; the point of primary importance is increase in " adaptation ". In particular, we must avoid the possible mistake of assuming that the complex is necessarily more " highly evolved " than the simpler. In one way it is so; advancing adaptation to an environment is shown in the form of steady development of fresh adaptations to specific features of the environment. The more fully " adapted " organism can respond differently to fine differences in the environment where the less " adapted " only responds in a less specific way to the grosser and more palpable differences. And this increasing power of appropriate response is embodied permanently in structure in the form of specialization of organs. It would be superfluous to illustrate this in detail from the history of an organ like the eye or the brain. But we have to remember that this connection of adaptation with complexity is subject to certain important restrictions. It is not mere complexity, but correspondence of structure in the subject of the evolution with the structure of the environment which indicates advance in adaptation. *Irrelevant* complexity is a mark of imperfect adaptation, and its absence may be an indication of a relatively late stage in the evolutionary process.

Evolution by " Degeneration "

Thus, if we consider the development of the vertebrate skeleton we find that one of the regular characteristics of the adaptive process is the reduction of complexity where the

complexity would stand in the way of complete adaptation. Consider, for example, the way in which the original pattern of the five-toed foot has been reduced to greater simplicity in the case of species (e.g. the horse, the ox, birds, &c.) where the five-toed foot would be ill-adapted to a creature's habitat. The presence of " rudimentary " vestiges in ourselves of organs once fully developed in the congeners of our far-removed ancestors tells the same story. Or, to illustrate from a different sphere, consider the differences between the structures of civilized languages and those of the speech of Australian aborigines and natives of Tierra del Fuego. What distinguishes the civilized language from a more rudimentary vehicle of human thought is not simply increasing complexity. Very imperfect types of speech frequently exhibit a complexity which is a hindrance to the accurate communication of thought and needs therefore to be got rid of. At the same time they may have no adequate means of marking distinctions which are vitally important. For example, in a sufficiently rude idiom, it may happen that it is possible to say " I eat flesh " and again to say " I eat meal ", but there may be no one word by which to say " I eat " without specifying anything about the character of the food eaten. Persons who use a language with a vocabulary of this kind are clearly very unfavourably placed for framing the most simple " general ideas ". Or the grammatical structure of the language may require you to use different forms of the word for " man ", according as you mean " two men ", " three men ", or " more than three men ". A complexity of this kind is clearly much more of a hindrance than of a help to the precise expression of thought. To make language into an ideal tool of thought it is desirable to eliminate from it all grammatical complications which are not strictly relevant to the exhibition of the formal character of the thought to be expressed. Hence the way in which " accidence " has been reduced in our own language almost to a minimum by the shedding of " inflexions " which English possessed at an earlier stage in its history, gives it a marked advantage as a vehicle of thought, over its cousin, modern German, in which the elaborate case system is still

retained for the noun. Perfect adaptation would combine the maximum of relevant with the minimum of irrelevant complexity. We must thus bear in mind that in the process of adaptation to a complex environment, growing complexity in an " organism " will be accompanied by the growing reduction of initial non-relevant complexity to simplicity. " Evolution by degeneration " will be a subordinate feature of evolutionary advance.

Stability of Environment Relative

Again we must remember that the stability of the environment which we speak of is only a stability relative to the developing subject for which it forms the environment. Change in the environment itself may have the consequence that the evolution of the subject environed takes the form of a *general* degradation. Thus up to the present the line followed by the evolution of organisms on our own planet has favoured the successive emergence of creatures of increasing intelligence and increasing delicacy and complexity of structure. But if the anticipations of physicists are not upset in some way beyond our present powers of conjecture, we must hold that in the course of ages our planet will become increasingly unfit to sustain the " higher " forms of life. The last survivors would be just those beings with the least delicate organizations, who would be able to hold out longest against the unfavourable conditions of the environment. Like the organisms of the earliest stage in the history of life on earth, those of the latest stage would be what we should class as " organisms of a low type ". Yet historically they might be said to be the most " highly evolved " of all, in the sense that they had the longest history of development behind them. I make this rather obvious remark simply for the sake of calling attention to a confusion I think I trace in the language of some evolutionary thinkers. It happens that we have reason to hold that man, the most intelligent denizen of our planet, is very much of a newcomer. Thus the " latest birth of time " here is also the being whom we rank highest in the scale. By a natural " fallacy of accident "

we tend to speak as though we could proceed to the generalization that the more recently " evolved " must universally be higher in the scale of being than the " less evolved ". It is therefore worth while to note that the connection is accidental. When we say that man is " higher in the scale of being " than the dinosaurus and the dinosaurus than the oyster, we ought not to mean simply that there were dinosaurs before there were men or oysters before there were dinosaurs. The order of rank in the scale of being is an order which we bring to our study of evolution, not one which we learn in the first instance from it. The latest descendants of civilized European men are not likely to be their superiors.

The best "Adapted" Type not necessarily the highest

In any reasoned forecast of the probable future of life on our planet, we must, I presume, expect that the types which will be able to persist longest will be some of those which long ago succeeded in adapting themselves pretty completely to the kind of environment likely to remain longest unchanged; those exhibiting complicated adaptations to a less screened and more readily modified immediate environment are likely to be the first to disappear under the pressure of change in the physical environment itself. (No doubt, account must be taken of the singular capacity of some of these more complex types, like our own, to modify their habits and so to bring themselves into conformity to a very wide range of differences in environment. But allowance for this capacity of self-adjustment can hardly make a difference in principle to the statement we have just made.) Thus there is a sense in which we might say that " low " organisms found, for instance, in the deep sea are more " completely evolved " than types like our own. They have early adapted themselves thoroughly to an environment relatively exceedingly stable; we, with a much less simple and more variable environment, are never so completely in harmony with our situation. But we should not, on that account, say that a deep-sea organism ranks higher in the scale of being than a man, because it is much more thoroughly adjusted to its

environment than a man is to his. So I have heard an entomologist predict the ultimate extirpation of man and the "higher" animals by the insects. Supposing this prediction to be some day verified, we might say that the victorious insect species had proved themselves to be more thoroughly adapted than ourselves for life on this planet, but it would still remain the fact that the "higher" had succumbed to the "lower". The point is, then, that even when we leave all specifically *moral* distinctions out of account, there is a real difference between a "higher" and a "lower" type of organism which is not identical with the mere difference between that which can persist and that which cannot. We cannot decide what is "higher" by merely discovering what will maintain itself most successfully. The only sense in which it is necessarily true that the "fittest" survives is this: that which survives in a given environment is fittest to survive in *that* environment. It may quite well be that there is a real standard of worth, and by the standard of worth that which persists most successfully may be the comparatively worthless. The most enthusiastic evolutionary biologist does not really base his estimate of the worth of a type on the consideration of its chance of survival, though he may sometimes talk as though he did so. Wherever he got his standard of worth, at least he did not get it from his evolutionary researches; he brought it to them.

Moral "Value" independent of "Origin"

(4) These considerations ought to make it easier for us to advance to a further proposition of first-rate importance. Considerations of evolutionary origin have no bearing whatever upon the principles of ethics. When we are discussing a question of right and wrong, good and bad, it is wholly irrelevant to argue that a proposed modification of the moral customs or the moral standard of a community must be for the better because it is "in the line of evolution", or must be for the worse because it is not in this "line". A priori, as Mr. Bertrand Russell has said, it is as conceivable that evolution should go from bad to worse as that it should go from good to better.

Or, at least, there is no reason to regard the second alternative as the more probable except on the assumption that the whole process of evolution itself is throughout guided and controlled by an intelligent and moral power which is not itself a product of the process, that is to say, that evolution is itself only an instrument in the hands of Providence. Unless we feel justified in regarding this assumption either as a known truth or, at least, as a legitimate postulate of faith, we have no ground whatever for supposing that the direction evolution is taking is that of moral advance.

To put the matter quite simply, the judgment " this is better than that " does not *mean* the same thing as the judgment " this has been developed out of that ". If we are to treat the truth of the second judgment as guaranteeing the truth of the first, we must be able to give a *ground* for our conviction that within a single line of development the later result is always better than the earlier. Such a ground has been found in the belief that the whole course of events is under the guidance of a wise and righteous God, or again (in my opinion, with less philosophical insight) in the belief that " the evolving world " itself has an immanent trend towards goodness. But both beliefs alike imply an ultimate conviction, not contained in the conception of evolution itself, about the unevolved and unevolving source of all evolution. What is more, neither belief would of itself justify the unqualified identification of the " more evolved " with the morally better. The firmest belief in the reality of a moral and providential government of the world, or in an inherent trend of the world-process to good on the whole, will not enable us to deny, what indeed seems a patent fact, the real existence of periods of moral and social deterioration within history. If it is not true, as pessimistic poets have thought, or professed to think, that an age of gold is succeeded by one of silver, and that of silver by one of iron, it is equally untrue that every generation is invariably brighter and better than the one before it. And even where it seems clear that on the whole the later age must be pronounced morally better than the earlier, it may be the case

that in particular points of virtue the advantage lies with the earlier. Thus the average morality of this country in our own day may be decidedly better than it was, say, in the eighteenth or the thirteenth century, and yet it may be true that the men of those earlier centuries were our betters in respect of some great virtues. Or, on the other side, it may have been a moral gain that we have lost the insular self-complacency which seems to have been characteristic of our ancestors of the early days of Queen Victoria, and yet it may well be that on the whole account, all deductions having been made for Victorian " Podsnappery ", the " Victorians " were morally better than ourselves. In any case, whenever we pronounce the later in " evolution " better than the earlier, we do not mean to be uttering the frivolous statement that the later is later. We mean to be appraising the result of an evolution by an *independent* standard which we bring to bear upon our study of the order of development, but do not derive from it. We may think the new wine better than the old or the old better than the new; in neither case are we thinking merely that the new is the new and the old the old.

Ambiguity of the term "Progress"

I can only account for the frequency with which the confusion between the " better " and the " later in the order of evolution " presents itself in a good deal of our literature of the last half-century by two suggestions. For one thing, allowance must be made for a rather elementary fallacy of equivocation, committed under the misuse of the word " progress ". " Progress " may mean either of two things, advance *in any* specific direction, or more narrowly advance in what is recognized as the *right* direction. Thus the medical man speaks of his patient as " making progress " when his health is steadily mending, and says that " no progress has been made " if the patient is no nearer recovery now than he was last week or last month. But he also speaks of the " progress " of the patient's disease, meaning that the man is becoming more and more completely diseased, and his death drawing steadily nearer.

From the medical point of view this is progress, but progress in a *wrong* direction. So in moral matters, a society may be " progressing " in the sense that it is becoming morally better or it may be progressing in the sense that it is moving steadily further and further on the broad road which leads to destruction. In the wider sense of the word, the later stages of any development mark a progress as compared with the earlier; the character of the development and the end to which it is tending become steadily more and more clearly marked. But the whole development may have been all along on undesirable lines, and the progress simply a " progressive deterioration ". Obvious as this is, I suspect that the mere equivocation between these two senses of the word " progress " goes a long way to explain why otherwise able men have persuaded themselves that they can discover what are the right lines in social and moral development by simply finding out what line is actually being followed.

The " Evolutionary Moralist " and Moral Tradition

Perhaps more weight should be attached to a second consideration. No student of evolutionary science is a student of science and nothing more. He is also a man of his time, brought up in a society with definite traditions and a definite ideal, and he cannot help sharing the traditions and aspirations of the group to which he belongs. Even the revolutionary, who is in revolt against much of the tradition, has been himself shaped by it. Like the rest of us, the scientific man has a rule of conduct to which he conforms; he conforms to the rule because he likes doing so, and he likes doing so because he has been taught to like it. He tends to prefer the moral practice of his own age to that of his " rude ancestors " mainly because it is the practice to which he has been trained; certainly not for the mere reason that it is the practice of a *later* age. But it is that too, and so, when he casts about for a reason for preferring the morality of his own age and his own social group, it is easy for him to persuade himself that the relative " lateness " in evolution is actually his reason. Take, for example, the pacificism

characteristic of the ethics of Herbert Spencer, in which nearly all the moral evils and a great many of the mere inconveniences of existing social arrangements are ingeniously traced back to " militarism " as their source, and " militarism " itself pronounced to be bad on the ostensible ground that in the course of evolution " industrialism " is a later and more " highly evolved " condition. It is clear, for one thing, that the argument is unsound. It is true that at earlier stages in our own history the distinction between the fighting man and the non-combatant was not marked as it was in the time when the *Principles of Ethics* was written. Self-defence and fighting generally had ceased by Spencer's time to be things which might be regarded by any man as normal incidents of his existence. But it is equally clear that " militarism " as much as " pacificism " is itself a product of the increasing specialization of the professions. A " militaristic organization of society " presupposes, for example, the existence of great standing armies with a thorough professional training, equipped on a large scale with scientific instruments of destruction and supported by a huge charge on the industry of " civilians ". None of these conditions existed in what Spencer loosely describes as the " militaristic " age of our modern European civilization. A war such as that through which Europe has just passed would have been quite impossible except as the outcome of the very development which has also created modern " industrialism ". Militarism and industrialism ought to have come out as antithetic developments characteristic of the same phase of the same development, the evolution of " specialization of function ".

Apart from this error about facts, it is surely clear that Spencer's ethical condemnation of militarism cannot really be justified on his own premisses, and that his true reasons for his convictions have to be looked for elsewhere. As far as the ostensible premisses go, they would equally justify the most militaristic of Prussians in his very different moral judgment. The great German war-machine is as much a late product of steady evolution as the British industrial machine. If we want to understand Spencer's attitude to military ideals and insti-

tutions, we are more likely to be helped by knowledge of the moral tradition of the Nonconformist circles in which he was brought up than by pondering his evolution-formula. If he made the formula condemn militarism, it was because he brought an already formed moral disapproval of war ready-made with him to his evolutionary studies. Spencer's procedure is thus exactly like Mill's, when Mill tries to justify his own preference for a highly virtuous life on purely Hedonistic grounds. In point of fact Mill liked virtue because he was a decent man and had been brought up by decent men. But having persuaded himself of the theory that pleasure is the only thing it is reasonable to like, he has to construct a hopelessly preposterous argument to prove that a jury of connoisseurs in pleasures with no moral convictions at all would be certain to recommend, and to recommend unanimously, a life of exalted virtue as the most exquisitely pleasurable of all lives.

Independence of the Moral Standard

It is most important, then, to insist on the genuine independence of the ethical standard. I do not mean that men's actual standards of right and wrong do not develop with the general development of their minds. It is notorious that the standards actually employed do develop. But the point is that we can judge these standards themselves; we can pronounce the moral ideals of different societies, as well as their practice, to be good or to be bad, to be high or to be low, and we do not mean by a " low " standard simply a standard we have found to be adopted by an earlier, by a " high " standard one we have found recognized by a later, social group. The standard of a society may be better or it may be worse than the standard of their grandfathers, just as their standard of demonstration in matters of science or their standard of approbation in matters of art may be better or worse. Considerations of evolutionary history may be important in all three cases as explaining how the standard recognized by an age has come to be what it is; they have no direct bearing on the much more fundamental

question of the rightness of the accepted standard. In morals, as in physics, *veritas norma sui et falsi*; no answer to the question how we have come to hold a belief is of itself an answer to the question whether the belief is true.

Indirect bearing of Evidence as to the "Origin" on question of Value

We must, however, admit that in an indirect and secondary way the question of origin may bear on the question of validity. If I am independently convinced that the moral theory or practice of our own age is better than that of some earlier age in the history of our society, this conviction may reasonably be urged as presumption that some particular feature of modern social life may really be morally an improvement. Thus if I compare the views of all parties in the age of the Reformation on the duty of enforcing uniformity in religion with the prevalent toleration of every kind of disagreement, I may find myself unable to give a direct answer to the question whether our acquiescence in "dissent" is a mark of moral progress or of moral retrogression. I may doubt whether we are more tolerant because we are more humane or only because we are more frivolous. It would then be a fair argument to urge that the growth of tolerance of religious dissent is an integral part of a development which, as a whole, I myself admit to have been an improvement, and therefore the growth of the spirit of toleration is itself presumably good. But it must be noted that the presumption only subsists so long as no direct reason can be urged for the opposite view. The general rule is that presumptions are entitled to count, so long as they are not negatived by direct evidence. Questions of origin may thus reasonably be allowed as bearing on the question of validity in moral matters, when there are no countervailing considerations. Where there are, the presumption derived from the history of origins may lose all its force.

To give a second illustration from a rather different sphere, consider the Spencerian theory that all religion has arisen from fear and respect of the ghosts of dead chieftains. (This par-

ticular theory is now regarded as discredited by anthropologists generally, but it will serve our purpose as well as another.) Supposing the theory to be made out as a theory of the origin of the belief in God, it is obvious that it still leaves the question whether that belief is true untouched, precisely as proof that an alleged truth of chemistry or medicine had first been suggested in the course of researches after the philosopher's stone or the elixir would leave the truth or falsehood of the chemical or medicinal proposition an open question. But if it were admitted that our ancestors' fear of the ghosts of their ancestors is the *only* reason we have for believing in God, and that this fear was irrational, *then* we should be entitled to say that there is a rational presumption against the truth of belief in God. But the allegation that there are no other reasons for that belief than the superstitious fears of our ancestors would be denied by the believer in God, even if he admitted that the belief had originally been suggested in this way. Thus, as against him, this or any other speculation about the origins of religion has no force until it can first be shown that the reasons he now alleges for his belief are worthless. To judge of the grounds for a belief simply by consideration of the history of its origin is to make just the same kind of mistake as that of the man who thinks he has explained what a thing is by explaining how it has come to be there.

" Origins " need to be studied without Prepossessions

These cautions are not, of course, meant to discourage research into the history of the origins and development of the characteristically human activities, art, science, morality, religion. The history of development, and especially of human development, is both a legitimate and a fascinating study, and it cannot be pursued with too great a detachment from prepossessions. If we are to arrive at results of any value, we need to discount our personal convictions, however justifiable they may be, about the worth of the thing whose history we are investigating. A Christian's conclusions about the origin and development of his own religion ought to be as " objective "

and impartial as his conclusions about the origin and growth of Voodoo or animal-worship; a European moralist should study the process by which monogamous marriage has become the rule of our own society exactly as he would study the development of polyandry among Tibetans. That the Christian regards Christianity as true and Voodoo as a horrible delusion, or the moralist monogamous marriage as a great moral achievement of humanity and polyandry as a degrading moral aberration, is a fact, but a fact which has no right to influence his researches into origins. But, on the other hand, it is equally true that when you have reached your final conclusion about origin and development in either case, the question still remains to be answered, is one of these religions true, or one of these family organizations ideally good, and, if so, which is it? And this question is not one to which researches into the evolution of beliefs and practices can, of itself, provide any answer. Most of the bitterness which has attended the promulgation and criticism of evolutionary theories might probably have been avoided if both parties to the dispute had been careful to remember that you neither explain what a thing is by saying how it has come to be there, nor explain how it has come to be there by saying what it is.

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CHAPTER XIII

The Religious Effect of the Idea of Evolution

SECTION I

Preliminary Considerations

Such is the subject on which I am requested to write. And first as to the spirit in which we must approach it.

It is assumed in the title that ideas in the sphere of science can and do affect religion. This is in itself a very far-reaching assumption. It implies that religion is susceptible of modification by influences which in themselves would not generally be regarded as religious.

I do not attempt to define religion. But the fact of such effective influences on it can be denied by no one who looks back at history. Take the development of the Christian religion. The forms which Christian ethics, faith, and worship took in their early stages were manifestly affected by the contemporary moral standards, philosophies, and modes of worship, Pagan, Greek, and Jewish. They were manifestly affected in later centuries by Roman Imperialism, by the obscuration of the dark ages, and by the Renaissance; and later still by the extension of knowledge of nature; by the study of other religions; by advance in philosophy; by historical criticism; and so on.

That is enough. Religion, however innate and deeply seated in human nature, however *sui generis*, and however

fixed and final its spiritual elements may be, has always been influenced in its form and expression by the conditions of human life; and of these conditions knowledge and intellectual activity are among the most influential.

It is therefore not disloyal to their Master for Christian men to consider the effect of the idea of evolution on their religion in its present form. It is indeed a duty. For some effect there must be. The nature of that effect will be, for the next generation, largely determined by the attitude towards evolution taken up by thoughtful men of our day.

This may seem a commonplace. But it is worth stating quite explicitly. For it is difficult for men whose faith is mature and settled to realize, to keep as a constant factor in their thoughts, that some of the elements in their own religious faith ought to be modified by increasing knowledge and experience; and that the young cannot think, and ought not to be expected to think, exactly on the lines of the old. We know indeed, on the Highest Authority, that there are truths which once even the most devout and faithful "could not bear", but which were, in another age, to be made known to men. Our unavoidable duty, however difficult, is to apply this knowledge in particular instances.

I may seem to overpress this. I do so to create intelligent sympathy for some of the readers whom I have in view. It is hard for them to approach this subject without prejudice. For example, there is a very telling contrast which is often drawn between "the passing theories of science" and "the eternal truths of God". This contrast is very common in apologetic literature, and still more common, unformulated, at the back of men's minds. It is quite honestly felt and expressed. But it is misleading, and is a fallacy. The fallacy consists in identifying "the eternal truths of God" with our present knowledge of them. It would be equally telling, and equally misleading, for a similar reason, to contrast "the passing theories of theology" with "the eternal facts and truths of nature". There are "passing theories" in theology as well as in science.

It must be admitted on reflection that all our sciences, including theology, are in various stages of incompleteness; and that in some the incompleteness is such as to include absolute error. Progress is being made in them all by genuine desire for truth; by accuracy in observation of facts; by putting forward provisional generalizations suggested by such observations; and by then provisionally adopting or rejecting or modifying these provisional generalizations as knowledge advances.

I plead that it is only in this spirit that a sincere seeker after truth can rightly approach the subject of this essay.

Some Personal Considerations

But now a few words must be said of a personal nature. The subject assigned to me in this volume may be interpreted as being to make either a forecast or a pronouncement as to the effect of the idea of evolution on religion. But it is plain that for neither of these duties have I any special qualification whatever. The only conceivable reasons for my having been asked or for my having consented to write on this subject are, firstly, my age: I was already the science master at Rugby School in November, 1859, when Darwin's *Origin of Species* was first published, and have therefore experienced the first difficulty in assimilating the implications of its teaching which a younger generation has escaped; and, secondly, that both before and after my ordination, now nearly fifty years ago, I have constantly endeavoured to combine, as in binocular vision, the religious and scientific aspects of truth. But neither my age nor my endeavour is a qualification for predicting what the total effect is likely to be, or for pronouncing what it ought to be.

I think it right, however, to say at the outset that I wholeheartedly desire that the effect of the idea of evolution on our religious life should be carefully, fearlessly, and sympathetically studied by persons at once devout and learned and in positions of authority; and that I personally have been led by experience to believe, as well as to hope, that the idea of evolution will

justify and promote a spiritual view of the world; will eliminate, rather than solve, some difficulties in Christian theologies; that it will purge, simplify, unify, and confirm a truly Catholic Christian Faith, and attract many to it; and will strongly reinforce motives for Christian conduct.

Another brief prefatory remark must be made. It must be remembered that there is no need for recasting religious phraseology because our thought of the method of creation has been changed by the idea of evolution. I do not find in myself, as a whole-hearted evolutionist, any inconsistency or dishonesty in using pre-evolutionist phrases in teaching religion, or in worship, provided that I am equally clear and explicit in explaining that such phrases belong to a past state of knowledge. We are all, for example, post-Copernican, but we naturally and truthfully use pre-Copernican phraseology. When what lies behind such phraseology is widely known there is no dishonesty in using it. In teaching religion, as in teaching science, we must at first use popular language, the language of parable. The idea of evolution is indeed to some minds the greatest help the world has had towards the interpretation of the mystery of life, and is not yet universally familiar. But the evolutionist may still honestly use in speaking of God and man and creation the language of parable, knowing that it is parable, and interpret it, when interpretation can be understood and is therefore needed. The change in expression is likely, I think, to be slow—indeed in some cases dangerously and wrongly slow in the hope of being inoffensive—and almost unnoticed; but the real change in thought may be very transforming and very effective.

No one dreams that evolution should be taught in the pulpit, any more than heliocentric astronomy, as a part of the Christian faith; but many feel that on the other hand to speak of evolution as dangerous, materialistic, unorthodox, and even heretical, or to ignore it, is unjustifiable, and also faithless and short-sighted. The world has suffered much from men's unwillingness in the past to welcome new light, especially from suspected or despised quarters. Let us think what may come

what surely must come, if science and philosophy, in their single-eyed pursuit of truth, should prove to be a great help and guide to man's spirit; a bulwark of faith in God and in Christ as His Revealer; and an inspiration to man to work for the Kingdom of God on earth. Why should they not? That is my hope, and that is my belief. I think the time has come.

On whom the Idea of Evolution may have a Religious Effect

There still remains one more preliminary consideration. We speak of the religious effect of the idea of evolution. By whom do I contemplate this effect as being felt? That is an important question.

I reply that I am thinking first of those who dislike the thought of evolution in connection with religion. I desire to win from them a careful study of this whole volume, and a sympathetic effort to understand and respect those who differ from them. And in the next place I am thinking of those educated men and women of our day who are alienated from all organized religion. The great majority of them are very far from being opposed, or even indifferent, to religion: they are not atheistic. But they find the popular, traditional, and apparently authorized presentation of Christian theology by the Churches confused and contradictory, or superficial and obscurantist, and, as it stands, to them impossible. I am thinking of their need—in many cases an unconscious need. I am thinking also of many educated people who have not forsaken the orthodoxy of organized religion, but accept it to meet their needs, *faute de mieux*; consciously desiring, however, and welcoming something deeper. I am thinking of the stream of educated boys and girls, and their prospects of finding the guide to thought and inspiration to conduct that our generation ought to provide for them. I am also thinking, as remotely, after a long time, to be affected, even of that substratum of "darkest England" of which we know so little. What religion will touch *them*? I do not dwell at length on this.

The need of a new presentation of the Christian faith is notorious. Moreover it is confessed by the authorities of the Churches themselves. Let anyone read the recent Report of the Archbishops' Committee of Inquiry on "The Teaching Office of the Cl rch", noting well the weighty names of the members of tha Committee. They frankly and fully admit "the failure of the Church to obtain a hearing for its message". Then note that the first among the causes they assign for that failure is the failure of the Church's theological teaching. Think of that! Let him go on to read the Report of a similar Committee on "Evangelistic Work". This also speaks of the same failure, but it goes a step farther. The former report lays the blame on the clergy and their training; the latter, as I think with far more insight and justice, finds the cause in the message itself, as given. I will quote from that Report only one sentence: "If the Church is to preach to this generation an evangel which will grip, it must come in some real sense as 'news'; news powerful enough to change the whole mental and spiritual outlook". News! in theology! These are not the words of some youthful enthusiast or of some aged crank who is persuaded that he has a panacea for all doubts and difficulties, still less those of critics equally regardless of heresy and authority. Think from whom they come. Similar expressions could be gathered from representatives of other Churches. It is the alienated, the unsatisfied, and the untouched sections of Christendom that may be profoundly affected by the idea of evolution.

Christendom is not a happy company of believers, united in Faith and Order, called on to resist a new heresy without further parley. It is seriously and dangerously perplexed by the new developments of knowledge. There is a very real need of such an exposition of them as shall show the harmony which science can introduce into the conception of life as a whole.

Moreover evolution is now no longer a mere theory which those who deal with eternal truths can ignore as destined to pass away. As a guess, a speculation, it has existed from the

earliest days of human thought; as a probable theory, based on botanical and zoological classification, but still unproved, it was in the minds of many naturalists more than a century ago. Darwin greatly increased the probability of the theory by suggesting the method of natural selection; and the last half-century of geology and palæontology and embryology has now proved that the method of creation of organic beings has been modification in descent through long ages of time. If anything is certain, this is certain. If we and the globe we inhabit are not mere illusion and dream, this is fact. Evolution may therefore be—must it not be?—a further revelation of Truth given by God through man, when the time was ripe, as to the nature of His Being and Presence in the world, a fresh glimpse of reality, a fresh light on life.

POSTSCRIPT

I think it necessary to say that this essay was written and sent to the publisher before I had the advantage of seeing any of the preceding essays; and that I have had no communication with any of the writers. I may add that I find that a leading thought in this essay was anticipated almost verbally in 1883 by Francis Galton, as shown n his *Life*, by Karl Pearson, Vol. II (1924), pp. 263–7. It did not come into my hands until this essay was in print.

I have not thought it to be included in the scope of this essay, nor essential to its purpose, for me to distinguish between the various neanings of the word "evolution". For example, I speak of the volution of the solar system, of a daisy, and of the spiritual faculties f man. But I am quite aware that the word evolution, applied to hese three subjects, means very different processes. The first, hough not accurately described as purely mechanical, yet is free, as ır as we know, from any contingent or volitional influences. It is onceivable that its results might be foreseen. If it had not seemed edantic I would have used for the solar system the word developlent, and reserved evolution and emergence for the more intricate rocesses in which life is concerned. The word evolution as applied a daisy or to the spiritual faculties of man, must not be taken to nply that the process is simply one of unfolding what was there efore, and to exclude the belief that an influence from without or om within has been and still is operating on it. No physical olution explains the origin of mind. Evolution is very far from vesting life of its mystery.

Those who wish to see how the relation of evolution to religion has been handled philosophically from several points of view should read the article on evolution in *The Encyclopædia Britannica.* I have set myself to consider solely the practical question how evolution affects religion, in the broad sense in which " the man in the street " takes evolution, viz. the fact that the method by which God has created the world is a continuous and orderly process, though full of mysteries we cannot yet explain. I hope that this limited attempt is worth making. J. M. W.

January, 1925.

SECTION II

The Purging and Dissolving Effect of Evolution on Theology

We must now come to the main subject of this essay—an attempt to estimate what effect is produced on a man's religion by his acceptance of evolution as a fact.

I find that nearly all my thoughts on this subject are suggested by personal experience, and conversation with a few friends, influenced of course by current literature; and that I can therefore only really describe how my own religion has been affected. I do not think that my experience was at all exceptional among my own generation of educated men; but it is certain that the young have arrived at similar results by much quicker routes, or perhaps quite unconsciously. I might, of course, in order to avoid the appearance of egotism, generalize my experiences, but by so doing they would become less truthful and less helpful. Moreover, much has been and is being written, by men far more competent than I am, to deal with this great subject on general lines.

The whole-hearted acceptance of evolution as a fact has profoundly affected my own religion; making religion a larger and more harmonizing element in my life, more secure also and sincere, and, as I am convinced, more Christian, in its two spheres which may be broadly described as those of thought and conduct, or more technically as those of theology and ethics or morals. In the former of these two spheres it has made me

more consistent in belief; in the latter it has been a constant—would that it had been a stronger!—inspiration to action.

I take the sphere of theology first.

What was the Theology that was Affected?

But let us be clear what we mean in this connection by that word " theology ". What is the theology which can be so affected? There exists no universal and permanent textbook or code of Christian theology. Theology cannot be defined as the conception of God and His relation to nature and man stated in specified books or documents—Bible, Creeds, Councils, Articles, Confessions, Legal Decisions, &c. All these are historic, something in print, and therefore so far unalterable. But theology unquestionably does alter; it develops; and it changes in developing. Theology means in fact to each of us that selection or rejection and that interpretation of such authorities and of such current traditions on religion derived from them, as, in our own age and in our own Church, are generally accepted as " orthodox ". That is the theology which is affected. That is alterable. Even if a Church allows no revision of its documents, and never withdraws a word of them, it allows, for it cannot prevent, changes in their interpretation and meaning. Orthodoxy does change.

And here it is worth remarking that orthodoxy, sometimes spoken of with impatience or even a sneer, is an indispensable element in the religious education of the world. It embodies our invaluable continuity with the past. It is also the fly-wheel of the machine; it keeps the pace of progress steady. The orthodoxy of one generation is never precisely that of the next. It gives full weight to traditional experience, while it is affected by all the serious influences and the ever-growing knowledge of the time. It keeps the Church together, while it moves on at a pace that frightens some, and disappoints others. Orthodoxy is a great stabilizing and uniting element in the evolution of theology. In fact no evolution in theology would be possible without it, for it is orthodoxy itself that is evolving.

Think of the orthodoxy of creation a century ago. There is in the Worcester Cathedral Library, among our early printed books, a copy of the *Nuremberg Chronicle*, a History of the world from the creation downwards. The primæval void is represented by concentric blank circles, with a Hand stretched over them. In the next page the Creator is shown as an old man modelling Adam out of clay, with animals standing round. Adam is finished down to his waist, and alive; the rest of his body is a formless lump of clay. I show this book sometimes to visitors, as Boswell tells us it was shown to Dr. Johnson, and they smile. But let us remember that this represented both the orthodoxy of the whole Church and the science of naturalists till the lifetime of some of us. Can we in the same breath admit that the orthodoxy of seventy or eighty years ago was temporary and mistaken on so great a matter, and still hold that the orthodoxy of to-day is final and correct? The retrospect of the past in which I am indulging is valuable if it forces this question on us, and demands an answer. *The orthodoxy of the past was based on the science of the past; and if the science alters and expands, so also must the orthodoxy.*

Is it not evident that the vast change of our conception of the created universe has affected in general men's thought of the Creator? What was conceivable, credible, and fully believed by early Semites, as to the nature of a God ruling a small tribe in what was thought to be the sole created world—a conception long accepted on their authority—became inconceivable, incredible, and is frankly disbelieved in presence of the infinities of space now known to us. Our Christian conception of God, adopted from Jewish tradition, was in fact small and childish; and it was of a kind that would not bear indefinite expansion. It was stretched, and stretched, till it burst like a bubble and disappeared. The disappearance of that early conception of God was followed in my case and in that of many of my contemporaries by a period of perplexity, of blankness, of waiting for light.

Pre-Darwinian Difficulties

Our next stage was certainly the result of study not of theology but of nature. We became acquainted with such writers as Humboldt, Lamarck, Lyell, Buckland, and Cuvier, and learnt a little botany. I and my contemporaries became convinced that evolution was a fact.

I not only at this time learnt more of the facts, but I also began to realize better the amazing order and significance of Nature, to which I must have been mentally blind before. Everybody *sees* enough to vindicate that order and significance —there is enough in the sight of a kitten, or an egg, or a daisy— if one can really think of what he sees, and realize its significance; but with some, like myself, it is only the accumulation of evidence from every quarter, or some opening of the eyes, that brings about the next stage.

I think that this sense of the significance of the Cosmos has also been inherited by the present generation. For the fact, then startlingly new except to a few scientists and readers of Aristotle, is now fully present to most minds, that this globe of earth—to look no farther—not only *is*, but *has come to be what it is*, through a process carried on continuously through unmeasured ages; has *become* a *cosmos*, with all the order and beauty which that word implies, out of a *chaos* of atoms. That is the impressive fact. *It has come to be.*

Then the fact of the antiquity of man was challenging our thought. For this element of time, as well as that of space, also necessarily affected our thought of God. Different degrees of importance are inevitably assigned to periods and events in human history according to the length contemplated as the total duration of that history. When men thought, as men thought less than a century ago, that mankind had only existed on this globe for " six, or at most seven, thousand years ",[1] the events of Jewish history or tradition and opinion were of far greater importance than they could be considered now, even if they were certainly historic. The perspective of time

[1] Pearson on the Creed.

is wholly changed. Prehistoric archæology, anthropology, and geology have unveiled a background of undefined but vast extent of time through which man has been created. The antiquity of man has involved an evolution of humanity, an evolution of ethics, an evolution of theology. It is impossible to leave this out of consideration. Conceptions of the God of a small people, formed during a few centuries, could not be identical with those that men form of the Creator and Lord of a humanity as we now know it, which has existed for, it may be, many myriads of years.

Most of the educated young people were, I think, in that stage of thought in November, 1859. We were, as I have said, evolutionists at heart. We had begun to realize the immense extent of the Sidereal Universe. It was incomparably more to us than it was to the writer of the first chapter of Genesis, who added incidentally that God " made the stars also ". Lyell and others had also familiarized us with the age of the earth, its slow and gradual formation, and the long succession of forms of life on it. We were becoming reconciled even to the thought of pre-Adamite man, and an undefined but possibly very great antiquity of man. And the effect of such extension of time as well as of space was, with the generation brought up as I had been, finally to dissolve the traditional theology we had inherited of Creation and the Creator, and we could form no conception to replace them. But simultaneously the fact that there should be this amazing Cosmos, and not only that, but also beings like ourselves, to whom the details and processes were at least partly intelligible, convinced us more than ever that there was some Purpose and Mind, in some way akin to us, who had created and was creating all things, but whose nature and method were hopelessly beyond our power to understand. Upon us, when in this state of mind, burst Darwin's *Origin of Species*.

Darwin's " Origin of Species "

The general effect of the book in altering the method of theology has been so often and so well described from different

points of view that I need say little. It certainly made an epoch in my life. It seemed to me at the time unanswerable. Darwin and Wallace had found in the " struggle for existence " a *vera causa* for the divergence of species, and for some if not all of the marvellous mechanisms and adaptations and forms and beauty of living things. Darwin seemed to have almost dispensed with a Creator, or at least thrown Him back into the infinite past. On second and third reading the book seemed to me equally unanswerable, though I could not accept it as a complete explanation. The co-operation of some Intelligent Purpose seemed to me necessary. But I could picture to myself no direct action of God on matter in creating new species or inventing the marvellous mechanism and variety and beauty of plants and animals, except such as that illustrated in the *Nuremberg Chronicle*, which I had finally rejected as childish and false. I was at a deadlock.

I did without the thought of God for a time; and strange to say I do not think my life deteriorated in any way, nor did I miss it much. I hoped, though scarcely expected, that the eclipse was only for a time, and retained all the old habits of religion, even of prayer, in the darkness. The " fly-wheel " was very useful then. At this time I remember also that I was giving a good deal of time to the study of parts of the Old Testament, and specially the Psalms, reading Stanley, Ewald, Colenso, &c., and studying parts of the New Testament. But I cannot remember that these studies as yet bore at all on the great problem raised by evolution as to the reality of Divine Action from without on nature and man.

I am venturing to say all this, not because I think that my personal experience is of any interest to anyone as such, but because it may serve to illustrate the stages through which a later generation passes too rapidly to notice and analyse—which it takes unconsciously in its stride; and thus to explain an attitude towards evolution which survives in some religious circles.

But then followed a further stage, which I do not feel so sure is part of the experience of the younger generation.

The primitive conception of God as a Being, with faculties

resembling but surpassing human faculties, was, it appeared to me, inevitable as the "first thought", when man's spiritual and speculative powers first developed, because man was the chief and highest visible agent possessing creative faculties. Hence anthropomorphism and mythologies were the inevitable mould in which primitive theology was formed; they provided the framework and symbols and language of early theology. These mythologies and symbols and words, when venerable and established by age, became hardened into solid facts, and were regarded as supernatural revelations; as facts from which equally solid inferences could be drawn. To use another metaphor, I came to regard our orthodox theology as a superstructure logically built up in the past on what were thought to be known facts, but were really metaphors, analogies, symbols, men's "first thoughts". These were naturally expressed in forms drawn from material nature, and had thus got far away from the spiritual facts, unexpressed and often inexpressible in words, which had been and are the real and permanent suggestion and ground for belief in God. I began to think that a time was at hand when men's first thoughts of God, however logically worked out into a system, would share the fate of first thoughts in every other science, and be superseded by "second thoughts" of a wholly different nature.

The Need of Second Thoughts of God

No one with any acquaintance with science could fail to anticipate a resemblance in this respect between the history of theology and that of other sciences. When we think of geography; of astronomy; of light, or heat, or electricity; of the origin of languages and races of men; or finally of the origin of varieties and species of animals and plants, we see how one theory has replaced another in all of these sciences. We shall, I suppose, admit that thoughts in theology also, in ancient Egypt, Babylonia, Greece, India were only first thoughts. Could it be denied that the same was true of Jewish theology, and therefore also of large parts of Christian theology, pro-

foundly influenced as it was by Jewish, Greek, and Pagan thought?

"Second thoughts" in theology became my hope, my clue, my goal in the search for truth. I think that perhaps this was, in part at least, the thought in Dr. Temple's mind when he said in 1857 that "theology would in future be based not on logic but on psychology". I did not, however, know of this saying till long after the period I am speaking of. To me this thought, that future generations would have truer conceptions of God than their ancestors, was a part of "the religious effect of the idea of evolution", and I think it must be so now with others. We were all searching and waiting for or had found "second thoughts".

I have thus briefly described how the idea of evolution enlarged our conception of God, and purged it of some of its childish errors. It "removed the things that are shaken, as things that have been made, that those things that are not shaken may remain" (*Heb.* xii, 27).

SECTION III

The Illuminating and Constructive Effect of the Idea of Evolution

In the previous section I described some effects of evolution on religion of a dissolving and destructive kind. Evolution seemed to banish God from the world into the infinities of space and time. And yet there was the Cosmos, unaccounted for; and there survived an unsatisfied desire, and a persistent and almost universal conviction of God's existence, even if unjustified by physical sciences. In this section I wish to indicate—and I can only do it by again more or less analysing my own experience—something of the later and quite different influences of the idea of evolution which have attracted less attention, the range and hopeful implications of which are still, perhaps, imperfectly realized by most of us.

Let me begin with an illustration. One of the curious exercises in mathematics which I learnt at Cambridge was the tracing of curves from their equations. I remember how in one case, as one of the two variables increased, the tracing point of the curve fled away from the origin to infinity and disappeared, and then, unexpectedly, on the instant, it reappeared at the very starting-point. That illustrates what took place in my religious experience. As the evidence and range of evolution increased, my conception of God receded farther and farther away into the infinities and was lost; and then, unexpectedly, it reappeared at the starting-point, the human spirit.

Evolution suggests or confirms Second Thoughts about God.

To me it was the idea of the evolution of *humanity* that suggested this reappearance of what I had lost. To others this idea has confirmed, what they had surmised on other grounds long before, that it is only in the study of man's nature that we can hope to find a clue to God's Purpose in Creation. Herein lies, as I think, the great service that the idea of evolution is rendering to theology. It has suggested, or it has confirmed, man's "second thoughts" about God.

It may perhaps be worth while to indicate the order in which this thought came to me. Evolution had been shown to be the method of creation of everything from the solar system to a daisy. Of that I had no doubt, though details of the method were still mostly unknown. And so orderly and interrelated is this Cosmos that it was impossible that it, including ourselves, should be, what someone has called it, "the outcome of an accidental collocation of atoms". Universality and regularity in method do not exclude or replace Purpose and Design. Why then not regard evolution as the method, (it is only a method), of a Creative Mind? True that the scale of space and duration of time of the working of that Mind appear to have no limits; equally without limits, and therefore equally indefinable, must be that Mind, if looked for in that

sphere. But may we not more hopefully seek it in human nature; not in infinities, but in the finite, in what we ourselves experience and grasp and are? There, in our own personalities, is something always at hand to everyone and known, though not through our bodily senses; something to which constant and universal appeal can be made—the only thing we really know. May not this be the most promising field to explore? We must seek for God within. Such were the words of Augustine: " Interrogate thyself, O man, and make of thyself a step to the things which are above thee."

We cannot but see that living organisms are the latest product of a vast evolutionary process, and that we men are, as far as this globe is concerned, the latest and highest result of that process. It must therefore be to the nature of man that we must look for the plainest indications of the purpose of the unseen and unimaginable Creator. Here are we, a ceaseless stream of material, sentient, spiritual beings, with intensely active life, intelligence, freewill, purpose, conscience, spirit, personality. In our material substance we are the dust of our mother earth; in our life and structure we are akin to the whole organic creation; but in our mind and spirit and personality—whence came they? it must be that we are in them akin to that unseen Creative Mind whom we may thus rightly call Our Father. It must be that it is in human personality we should look for traces of Him. This is a great, perhaps the greatest, constructive effect of the idea of evolution.

And the effect of thus fully accepting the idea and fact of the evolution of man himself is to carry us a step further, a great step. If man is the climax, as far as known to us, of living beings, is it not because he is the incipient vehicle of self-expression, the incarnation in some degree, of that Unseen Creator Spirit Himself? That is, in briefest form, man's " second thought " of his relation to God, suggested or confirmed by evolution; the belief that man has himself evolved, and is evolving, under the influence of the Indwelling Life and Spirit of God. Such was the illuminating thought that came to me in outline long ago, that God is to be sought for

and approached and understood within. The search for God was not to be abandoned but renewed, and success was in sight.

Contrast of Past and Future Effects of Evolution

I want my readers to pause here for a moment. The dissolving and destructive effects of evolution on *past* orthodoxy, and the gain of truth by accepting those results, are now so obvious that my readers, perhaps, wonder that the last generation felt any such fear or hesitation or struggle as I have spoken of in accepting them. It may be thought that at any rate the difficulties and controversies are now all over, and done with. But in fact the idea of evolution has only just begun its greater and constructive work. It has been clearing the ground. The new generation is now called on to study with courage, faith, and honesty the constructive teachings of evolution in all its aspects; and to trace and assimilate their far-reaching consequences. I have dwelt on the past because the general acceptance by the whole Church of Christ of one part of the lesson—I would rather call it the revelation—of the method of evolution, is an assurance of the ultimate acceptance of its further revelation.

I confess, however, that I have been doubtful whether I shall not be transgressing the limitations implied in the wording of the subject assigned me if I go further. It may be rightly said that, strictly speaking, the effect on theology of the idea of evolution terminates when it has been shown that the evolution of man suggests, or necessitates, as a basis for theology, the study of God as Indwelling. It may rightly be said that it must be for theologians, rather than for evolutionists, to explore the forms that on this basis theological language and doctrines must take. I shall, however, take a wider view of the intended scope of this essay; and attempt to indicate some of the ways in which the idea of the evolution of humanity is already widely affecting, and as I think illuminating, orthodox theological opinion on some of the gravest subjects. The words I quoted above from the Reports of the Archbishops' Committees still

ring in my ears—" failure of the Church's theology "; " the new Evangel "; " the message that will grip will come as ' news ' ". Does anyone doubt the Church's need? Yet what are Christians doing in reply to this challenge? Is a message, a revelation that will come as " news " impossible? God forbid the thought! I do not forget the proverb about fools and angels; but as an old evolutionist, and as a convinced Christian, I feel bound, however insignificant I may be, to use this opportunity given me for saying what I believe to herald the new Evangel.

I believe the idea of evolution to be a great and still unappreciated factor in guiding man's reason in search for truth.

In the first place it is of course obvious to everyone that this " second thought " suggested by evolution, of God as to be sought in His self-revelation in humanity, is no *new* thought. Historically speaking it was not the result of the theory of evolution. It is very old. It was anticipated in the pre-Christian world, as everyone knows, and by no means for the first time, in that grand passage of Deuteronomy. " This commandment which I command thee is not hidden from thee, neither is it far off. . . . But the word is very nigh thee, in thy mouth, and in thy heart, that thou mayest do it " (*Deut.* xxx, 11–14). Here, six centuries before Christ, is the vision of the Light within, and the looking forward to it as the goal of religion. We see it in the *Daimon* of Socrates, and in the faith of Antigone in the eternal origin of right. We feel it in many of the Psalms. It is of the essence of Stoicism. That it underlay and was the foundation of the teaching of Christ about God could be amply demonstrated from the fourth Gospel, and from the expressions used by St. Paul and later writers as to the indwelling Christ, and the indwelling God. The same thought is common to Augustine; to the long line of Mystics; and it permeates later theological and devotional works. It is no new thought that the Divine Spirit dwells in man's own breast. There is no difficulty in acquiescing in this belief in the " Light that lighteth every man ", as a supplementary, and perhaps an ultimate, conception of God.

But yet it seems to me that the idea of the evolution of

humanity has both transformed the way in which that thought of God is presented to us, and has also made it more of a piece with our other experiences and knowledge; and that it has given to this thought scientific confirmation and status, and final supremacy over all other conceptions of the relation of the human to the divine. It has given a basis for a common purpose in life, the absence of which is a cause for restlessness and pessimism.

The idea, the fact, of the physical evolution of humanity has led men to see continuity, order, law, also in the spiritual evolution of humanity; and this conception of continuity in spirit has gone very far in displacing what had been previously imagined and accepted as the nature of God's relation to man. The contemplation of the world of matter and life and spirit as a scene of orderly and continuous development is now rooted in the thinking world, accepted as axiomatic. No exception is tolerated. The evolution of man's spiritual nature is established. Morality, conscience, are continuous with intelligence, and are of the nature of things. The thought of a Transcendent God is not banished by the knowledge of the gradual evolution of life; but that knowledge carries with it the conviction that God is not to be found by us in nature apart from man, but only as the Spirit dwelling within us, " bearing witness with our Spirit that we are the children of God ".

In laying down dogmatic statements about God, Christian theology has in the past trespassed far on the unknown; it has reverted to the imagery of primitive mythology and has been misled by it. In other words the acceptance of the spiritual evolution of humanity has made the thought of God as revealed in humanity the primary factor in religion, and the endeavour to understand and co-operate with the Indwelling Spirit of God its primary aim. All speculation as to what is outside ourselves, the Transcendent Creative Power behind nature, is to be transferred to the metaphysician. It follows that less and less value is being assigned to the traditional interpretation of long past and imperfectly known historical events, and to the

metaphysics of past centuries; none of these can be for ever *de fide*, and more and more value is assigned to present human experience. Moreover, the idea of evolution, besides contributing greatly to our knowledge of God's relation to nature, has immensely extended our conception of the range of human experience and duty, and has helped us to interpret it.

Some Special Effects on Theology

But it is time to pass from these general considerations, and to illustrate them by considering some special instances of the illuminating effect of the idea of evolution on our present orthodox theology. The first illustration I take will appear at first to show rather the destructive than the constructive effect of the idea of evolution. And here I recur as before to a description of my own experience.

The evolution of man from lower forms of life was in itself a new and startling fact, and one that broke up the old theology. I and my contemporaries, however, accepted it as fact. The first and obvious result of this acceptance was that we were compelled to regard the Biblical story of the Fall as not historic, as it had long been believed to be. We were compelled to regard that story as a primitive attempt to account for the presence of sin and evil in the world.

It might have been easy for us in the light of science to treat that story, like those of the Flood or of Babel, as imaginative, if it had not been for the close connection, which has characterized Christian theology, between the doctrine of the Fall and the doctrine of the " Atonement " through Christ's self-sacrifice. This connection is chiefly based upon isolated words of St. Paul which reflect the teaching of the Rabbinical schools in which he had been a learner. But these actual words, it must be remembered, were then regarded as the very words inspired by the Holy Spirit, and could not be questioned. The association of the two doctrines provided a logical sequence and a connection with Judaism which commended it to the human mind, so that it had long been the very core of Christian teaching. John Wesley, for example, was but echoing

the long-standing Christian tradition when he said that "the Fall of man was the very foundation of Revealed Religion; and that if it were taken away the Christian system is subverted".

But now, in the light of the fact of evolution, the Fall, as a historic event, already questioned on other grounds, was excluded and denied by science. The Fall, be it observed; not sin; but that particular speculation as to the origin of sin.

What view of the origin of sin will finally result from the acceptance of a gradual emergence of the human from the animal is perhaps not yet clear. But the old view is gone for ever.

The obvious way to regard sin in the light of evolution is as a survival and rebellion of the animal and lower elements in man, after the emergence of those higher moral and spiritual elements in him which make him human, and have begun to claim control. In all spheres evolution involves struggle; no wonder that it does so in the sphere of human nature. The struggle is recognized by St. Paul: "I see another law in my members, warring against the law of my mind". This struggle is recognized by evolutionists. I hope T. H. Huxley's words in his Romanes Lecture (1893) will not be forgotten. "Let us understand," he writes, "once for all that the ethical progress of society depends, not on imitating the cosmic process, still less in running away from it, but in combating it."[1] "The one supreme, hegemonic faculty, which constitutes the essential 'nature' of man, . . . holds up the ideal of the supreme good, and demands absolute submission of the will to its behests. It is this which commands all men to love one another, to return good for evil, to regard one another as fellow-citizens of one great state."[2] Is it more than a verbal difference between Huxley's "supreme hegemonic faculty in man" and St. Paul's "Spirit of life in Christ Jesus" (*Rom*. viii, 2)?

The abandonment of the belief in a historic "Fall" of a primæval pair of human beings has removed one of the great obstacles to the acceptance by our generation of the

[1] *Collected Essays*, Vol. IX, p. 83. [2] *Ibid*., pp. 74, 75.

Christian Faith which had required that belief. Yet taken by itself it certainly tends to create, as well as to remove, a difficulty. For if there was no historic Fall, what becomes of the Redemption, the Salvation through Christ, which the universal experience of Christendom proves incontestably to be a fact? How does Jesus save His people from their sins? *He makes men better.* That He does so, that is to say that those who accept Him as their Lord and Leader are made better, is a fact. The question is urgent. It is mainly, I think, because the Church is not clearly and truly facing and answering this question that it is losing its grip. We cannot do without a Gospel of Salvation. Can the idea of evolution help us here? It is to this, the most serious of all religious questions, that we are now brought.

In the first place the question " What is sin?" must be answered. The answer of the Christian evolutionist will be: Sin is the voluntary surrender of a man to his lower instead of to his higher impulses. Man, being in process of development, sins when he reverses or retards that development by giving the rein to impulses which are condemned by what Huxley called the " supreme hegemonic faculty ", and what St. Paul called " the law of his mind ".

Evolution and Soteriology

Evolution is now approaching the citadel of our Christian Faith. It is affecting Soteriology and Christology. The fact must be faced.

In dealing with q. .tions so closely connected with the Person and Work of Christ we are indeed treading on most holy ground. But believing as I do that the establishment of the fact of evolution in the spiritual life-history of humanity is a revelation from God of His relation to man, for me to avoid examining this subject now and here would be faithless and cowardly.

I have said that evolution is approaching the citadel of our Christian Faith. Is it approaching that citadel as an enemy to be repelled at all costs? or is it to be welcomed as

a reinforcement to its gallant defenders? *I believe it*, as I have already implied that I believe it, *to be a reinforcement.*

I preface what I shall say on this grave subject by reminding my readers that in the Revised Version of the New Testament, which represents mature, accepted, and conservative scholarship and orthodoxy, the word "atonement" is no longer to be found. *Its connotation is now quite misleading.* Hence everyone who wishes to learn or convey the teaching of the New Testament will avoid using the word "atonement". Christendom has finally abandoned the Patristic and Anselmic doctrines which, from inevitably imperfect apprehension of New Testament phraseology, and from reversion to Jewish and pagan modes of thought, represented the sufferings and death of Christ as a sacrificial or forensic transaction between Beings in the Spiritual Sphere. Man's personification of God had misled him. We do not and cannot know God in such a way as to justify us in attempting to dogmatize as to the effect upon God of the death of Jesus Christ.

It is the unique and undeniable effect upon man of the death of Christ that is now the central object of our study. Here is no mythology, no product of imagination, no supposed logical inferences which may be doubted or disbelieved. Here are verifiable facts. The Cross has in some way brought men to a new realization of their relation to God. Its power is, I believe, best revealed when we stand before it as silent as did the writers of the Gospels. I shrink from speaking of it. Words may teach; they also limit and define what is in its nature limitless and indefinable. The Cross appeals to the Divine element in human nature, and has unique power to call it out into man's consciousness. Our instinctive reverence for self-sacrifice for others is a witness to a principle of conduct far higher than any form of self-seeking. It is the call of Love.

The relinquishment of the old attempted explanations of "the Atonement" has not robbed the Cross of any of its significance or power in the salvation of man. If salvation by the Cross has now come to mean for Christian men salvation from sin itself, not from the *penalty* of sin, "salvation" has

become more real, more verifiable, than before. It is the sins of the world and our sins that He who died on the Cross is taking away, by making us better. Salvation is not then thought of as an escape from hell; but as a lifting us all out from living lives unworthy of us. Religion so conceived is not the art of winning heaven, but the effort to become better and to work with God. There is no clearer evidence of an uplifting Power acting on humanity than the flash of spiritual illumination that shows man what he is and what he may be. That calls out fresh power. It strengthens mind, hope, and will. It was this illumination that Christ gave to the world by His life and death.

Evolution and Christology

But when we have defined the change wrought in men's minds with regard to "sin" and "salvation" by the acceptance of the idea of evolution, we have still to face the great question: What does the evolutionist think of Christ? Whose Son is He?

The idea of evolution affects Christology because it assumes and implies *continuity* along with advance in creation. And it is this idea and fact of continuity, impressed on us from all quarters, that is now determining what men are able to believe concerning Divine action in every sphere. The evidence for continuity everywhere is overwhelming. The implicit or explicit recognition of it among educated people, and a general sense of it, are becoming universal and axiomatic. Think of it as illustrated by one example only—the earlier essays in this volume will doubtless provide many more—continuity in the matter of intelligence. What a chain it is! Begin anywhere: with your own intelligence as you read, or mine as I write. First go down the chain. Intelligence is not confined to those who can read and write. It is shared by every human being. It is shared by animals. It is not limited to animals. Plants cannot be denied a share of it. It is found in roots and leaves and flowers. Go down farther still; and farther. You cannot find the end of the chain. And then go up. Our minds are continuous, homogeneous, with the greatest minds and souls that have

ever lived on earth. We are utterly unable to account for the brilliance of genius in any sphere. But there is continuity. To us intelligence, mind, spirit, is now seen as one long continuous chain, of which we see neither beginning nor end. We are perhaps at least as far from the top of it as we are from the bottom.

Continuity was not the prevailing thought of the old world, but its opposite. In every sphere of observation discontinuity was assumed. Wind and fire, birth and death, disease and misfortune, eclipses and comets, were all in some way related to a World and Beings other than the visible. There were, of course, some uniformities of sequence familiar; but nothing approaching to the idea of a universal reign of law was contemplated. Anything exceptional in the experience of the old world was at once referred to the action of Beings, Personalities, in another, but associated, sphere of existence, as it is still among primitive races.

To us, on the contrary, the conception of continuity has become, as I have said, axiomatic. It is not that men are now desirous or driven to reject the spiritual; they were never more conscious of it. It is not that materialism charms them. It has been found wanting, impossible. But they cannot accept a duality, a broad gulf between the natural and the spiritual. Belief, however, of that broad and impassable gulf has descended to them from primitive times, as a part of religion, and has affected and been sanctioned by Christian teaching. It is imbedded in the language of religion. It is the "first thought". But it does not fit the facts.

Let me explain yet further. It has been the universal assumption in the past that there were two separate spheres of existence, and that these were wholly distinct in kind. They were regarded respectively as natural and "supernatural". Exceptional occurrences in the natural were to be explained as caused by the irruption of the supernatural into the natural. Religion originated and has been largely concerned in dealing with these supposed irruptions. Parts of Christian theology have been occupied with them. These were "first thoughts".

But now the human mind—ought we not to say under the continuous teaching of man by the Spirit of Truth?—is rejecting the whole conception of this irruption of one sphere into the other. It identifies in kind what we have called the supernatural with the natural. It makes the spiritual and the natural continuous, and equally divine. If God has ever been anywhere, He is here among us now. This identification is, as it were, regularized as well as illustrated by the idea of evolution. This is the needed continuity, gained not by denying or degrading the supernatural, but by raising the natural into entire continuity with it.

Presuppositions on which Earlier and Later Thoughts of God are Based

In a world and at a time in which the whole tradition and vocabulary of religion were based, not on the idea of continuity, but on the entirely different and incompatible presupposition of duality, Jesus was born and lived. On the one hand was seen existing the natural sphere of human life and ordinary events; on the other was vividly realized in imagination a quite distinct non-natural sphere, in which spirits, good and evil, dwelt, from which at times at their will they passed into the natural sphere. Of all nations that in which Jesus was born was the most serious in its faith in such a duality.

It is plain that Jesus was at first to His family and neighbours a man, a carpenter, and no more. Ere long He was seen by a wider public as a Teacher, a Prophet; as One "who spake as never man spake"; on whose words "the people hung, listening", as One who saw the saint within the sinner, and whose call was irresistible; as One who was the healer of men's bodies and minds. He was not as other men. What was He? The Saviour of every age is too great to be perfectly understood in any one age.

How could His followers, with the strong presuppositions that I have spoken of rooted in their minds, account for Him otherwise than as a visitor, an irruption, from the other sphere, come down from heaven to be incarnate in Man—the Son of

God? They were indeed right in seeing Him as Divine, as the Manifestation of God. But were their presuppositions right?

At the present time the facts that Evolution and Continuity are characteristics of the method of the Creator of the world are suggesting—ought I not to say are demonstrating?—that the duality, the dichotomy, the essential difference of the two spheres, natural and supernatural, was but a passing theory in the long history of man for explaining the mysterious combination in ourselves of the spirit with the body. The facts of evolution and continuity are indicating that the chain of mind reaches up to the Creative Spirit, to God Himself, and that the supreme manifestation on our earth of the Divine in that chain is Jesus Christ. This is not to abate one jot of the Christian claim that Jesus was the Manifestation, the Revelation, of God in humanity, such as none other has been. Not one jot. It is not to lower Christ, but to raise our thought of man; it is " taking the manhood into God ".

This a Subject for Theologians rather than Evolutionists

This is not the place to pursue this subject further. As evolutionists we submit this thought to theologians, as the basis for that fresh presentation of Christ to the world which is so much desired. But as also students of the Bible some of us, from this point of view, would urge that the Gospels studied in the historical spirit do more than bear out this interpretation; and that the Epistles, and the spread of Christianity, and its early literature, and the future unity and universality of Christianity, are inexplicable without it. The Sonship to God, which Christ claimed for Himself before Caiaphas, and for which He was declared guilty of death, He claimed for all mankind; a relationship to God which implied continuity of nature. The Gospel that St. Paul preached (if one excludes all his efforts to persuade Jews that the Christian Faith was a logical expansion of their own) was that all men were the depositaries and inheritors of God's Spirit, called to be saints and fellow-workers with God. That Gospel, and the hopes and courage

and energy it supplied, was the message that " gripped " the world.

Here is a field for hopeful work. And let us not fail to note that evolution not only suggests that it is in human personality, as sharing in the Divine nature, that we shall best seek to find God, but also, by insisting on continuity, it leads us straight to the One Manifestation of God in which men have most fully found and seen and known Him.

The Church, with its scholars and philosophers and all its teachers, is challenged by the fact of evolution to read the New Testament and early Church History afresh in this light; and to see if man's " second thought " of God is not the underlying truth which an earlier age could not possibly express, except by partially transforming it so as to fit their own presuppositions which we now reject. We are challenged to interpret Christ afresh. Can we doubt that the old truth, that Christ is verily the Saviour of the world, thus rediscovered and re-expressed, will " grip " now?

Some further Remarks

One or two more reflections may perhaps be permitted.

It is not a heresy to deny the duality of the spheres of the natural and supernatural. No New Testament writer or Church Council ever thought of explicitly asserting that duality; any more than they asserted as a part of the Faith that the earth was flat, or that the Ptolemaic system of astronomy was correct. They were all assumed. The facts of night and day and summer and winter remain, but are now otherwise accounted for. And the same is the case with the great fact of the Redeeming work of Christ. It remains; and it is explained by the light it casts on the goal to which man is advancing, and by the inspiration it affords to the efforts necessary to effect that advance. Christ shows us that we are His brethren, His fellow-workers, sharers of the Divine Life, trusted by God to be His stewards and agents; showing us also an example of the principles of life that help to lead us upwards. So He saves us.

I said in my first section, that the fact of evolution "eliminated" certain difficulties in theology. This opens a subject too large to deal with here. Many illustrations could be given. I can only very briefly indicate one part of the scope of this remark.

Theologians know that in the earliest centuries it was the humanity of Jesus that was called in question. It was a phantom, some men urged, not a real man, who died on the cross. Hence it was necessary in the Creeds to assert that Jesus was truly man, born of a woman, and that He suffered. In later centuries it was His Deity that was called in question; and the combination of two different natures in one Person has been the subject of endless discussion. What did He say and do and suffer and know as man, and what as God? The path of orthodoxy on this subject has always been an extremely narrow and slippery *arête*, on which few apologists and theologians can travel far without sliding down on one side or the other. All this disappears if duality, in any other sense than that in which we recognize it in ourselves, is seen as a provisional and passing theory.

One further remark. There are doctrines about God, doctrines about Christ, and doctrines about man. They have been studied separately. But under the influence of the facts of evolution and continuity, they are beginning to be studied together as parts of a whole. Doctrines about God, taken by themselves, lead away into metaphysics, out of the range of common men, and scarcely bear on religion. Doctrines about Christ, and the union in Him of two natures, the human and divine, have led to much perplexity and contradiction. Doctrines about man have been largely inherited from a primitive past, and have scarcely yet been Christianized. That the Christian doctrine of man is to be sought in the experience of Jesus is no less true than that the Christian doctrine of God is to be sought there. Jesus Christ is a Revelation of Man as well as of God. The idea of evolution is thus leading us to the study of this Revelation and to a Christian doctrine both of God and Man.

That is, as I firmly believe, the truth; seen as soon as the root ideas and facts of evolution, and the continuity involved in it, are in full possession of the mind. Here is the hope of a "message that will come as news", "an evangel" that will "grip".

SECTION IV

The Direct Religious Effect of the Idea of Evolution on the Popular Standards and Motives of Morality.

I have been dealing with the effects of the idea of evolution on theology, and through theology on religion. But a few words must now be said on its direct, less definable, but scarcely less important effect on popular religion.

We all know that there are popular standards of conduct, of practical morals, and that there are motives which move men to right conduct which, however they have arisen, have now no conscious and traceable relation to a man's theological beliefs. To analyse the nature of such motives is the work of moral philosophy, and it does not directly concern us here. But I do not think it can be denied that these motives should be regarded as religious. Who can deny that his own standards and motives for conduct in daily life can rarely be traceable directly to his theological beliefs? and yet they are part of his religion. Conduct, character, motives, also form unquestionably a very large fraction of the religion and teaching of Christ. Whatever therefore affects conduct, character, motives, affects religion in a corresponding degree. It is not necessary to dwell on this at any greater length.

But let me give one illustration—I think an illuminating one. I was present, some few years ago, at a diocesan conference of clergy and laity at which a clerical speaker had urged that Christian principles should be openly recognized and avowed in the conduct of business. The Bishop asked a well-known and highly-esteemed business man in the audience

whether he had ever, in any business meeting, heard it remarked that some proposed line of action would, or would not, be Christian. He thought for a few moments, and then replied: "No; but I have more than once heard it said that it would scarcely be 'cricket'. And that," he added, "always settled the matter." Is not that religion?

There is unquestionably such a standard of rightness existing in all classes among us. It varies with the environment. But it exists everywhere. It is of slow growth. It is, of course, due very largely to Christian influences, continued for many generations down to the present day, fostering the development of the seed of divine life in man. A certain Christian standard has become indigenous among us, and it is rising. It is the work of myriads of good men and women, of faithful teachers and preachers. But it is not now consciously dependent on any theology.

This standard is affected by all the influences on men's environment, and it therefore becomes a very important consideration what effect is being produced on it by the popular acceptance of the idea of evolution. The subject needs a far more thorough examination than I can give to it; but I offer a few observations.

If the general results on theology that I have indicated in the earlier sections are really taking place; that is, if our Christian theology is being purged of some of the crudities it adopted from early science and from other errors and irrelevancies; if the continuity of the human with the divine, and the consequent sense of the divine within, are becoming central doctrines in religion, and strong incentives to action, then I think there necessarily follows a transvaluation in popular religion, and a corresponding rise in popular moral standards and motives.

Direct Effect of Evolution on Society

But besides this, the idea of evolution is acting directly on popular religion in several ways. It is changing our conception of man's status from that which was stamped on it by

primæval and Biblical tradition, which is still affecting our theology. That theology has perpetuated the impression that man is the one great failure in Creation; that men are fallen and helpless sinners, of whom a small fraction, by a merciful afterthought of the Creator, may be saved, while the vast majority are wasted and lost. In the light of evolution man is being seen from another point of view; as in a stage of hopeful progress towards higher achievement. He is seen as a spiritual Being, already risen immeasurably above his remote and lowly origin; already sharing consciously in some Higher life; already capable of partially understanding some Higher purpose and of co-operating with it; already striving for further communion with some Higher Power and Will. What power may not this sense of vocation, of dignity, of co-operation with the Divine create in man!

Again the idea of evolution extends all our horizons; it is a great expanding and educational influence. When human life is regarded as a stage in this vast age-long drama, men see themselves in truer proportion. Tolerance is promoted, active tolerance, passing into mutual respect. Action, initiative, are pressed on us. Are we giving expression to the best in us? Are we helping forward the subjugation of the animal in us, and the dominance of the divine? These are becoming the true tests of the Christian life.

The idea of evolution and continuity is also teaching the world to see that while in our present state historical and metaphysical creeds are necessary, yet religion is something wider and greater than they. I know nothing more hopeful and inspiring in the outlook of religion than this one fact: that while much of popular religion is alienated from all organized churches, it has never faltered in its reverence and honour for Jesus Christ. He is " verily the same yesterday, to-day, and for ever ". If the religious world is able to see that, as a fact, much so-called agnosticism is not incompatible with this reverence for Jesus Christ and with the truest service of God, this will unite the whole Christian world in spirit, and lift us all to a higher level.

Altered Relations of Science and Religion

Further, the popular religion is being affected by the change which is taking place in the mutual relations of science and religion.

A great and highly beneficial change has indeed already taken place in those relations. Christian apologists used to take the line—some do so still—"Science deals with one sphere, the material, the natural; religion deals with another, the spiritual, the supernatural. We need not interfere with one another. You mind your business, and we will mind ours."

This view of things has completely broken down. Neither party can acknowledge such an artificial division. We are fellow-workers in exploring the whole.

Both parties have learnt much in the last fifty years. Let me give one illustration. Had a volume of essays on evolution been contemplated fifty years ago, anyone who suggested that evolution had a *religious* aspect would have met with little but contempt or anger. The most advanced and influential evolutionists were then arguing that the reign of law was established and must be universal; that no event in the physical world took place without a physical cause; and that did we know all, we should see that human action was as fully predetermined by physical laws as were any other events in the universe. All resulted from the collocations and potencies of primæval atoms, and could conceivably have been mathematically predicted. I myself have heard Tyndall and others dilate on this prospect like men inspired. This was sheer determinism, and excludes the idea of moral responsibility.

And if the study of evolution has on further thought carried its most ardent supporters far beyond the paradox of determinism, it has had a similar effect on theologians. Religion used to be sharply divided into natural and revealed. It was thought impossible that a man who held no Christian or at least no Jewish form of theological belief could be "religious". This identification of religion with a special creed is giving

way. Religion is the sphere of all that is best in a man; of all his highest moral and spiritual faculties, practical, emotional, speculative.

The co-operation of science and philosophy with religion is already a fact, and it is beginning to affect the non-theological world. It is being now surmised that the purpose of the Creator may be traced in the gradual development of the universe, and that consequently the highest human aim must be to co-operate with this purpose so far as the limitations of human faculties permit.

Evolution and Continued Life after Death

It is the work of the theologians of the Church to formulate for the world the wider faith now being revealed to the world. But there is one question which is put to the evolutionist as such, and cannot here be quite passed over. Does evolution throw any light on human immortality? or, to be more precise, on the question whether man's spiritual identity will be, or may be, continued after the dissolution of the body?

I think the answer must be that men as yet do not and cannot know what their personalities will experience after death; and that it is good for them that they do not know. Good for them, because each stage of life has its own function, and a knowledge of the next might disqualify them for their duties of the present. Here we are stewards of Another, and if faithful we shall be entrusted with that which shall be our own. The words of Horace are true in a wider sense than he meant:

Prudens futuri temporis exitum
Caliginosa nocte premit Deus.

But on the other hand Christian conviction and experience, and the all but universal belief of man in past ages, cannot be set aside. Moreover, the idea of evolution and continuity, along with the conception now closely associated with them of a divine element combined with the human spirit, does, I think, contribute to and solidly confirm the hope and the belief that

if and when that divine element in a man has so predominated, and so transformed his personality that he is himself a centre of spiritual energy, then he is already living the eternal life. And I have long held that this is the teaching of the New Testament.

To put this more briefly, the conviction that springs from the idea of evolution, that the spiritual element in man is continuous with the divine, is in other words a conviction that there is something in us independent of time. If a man is individually, while on earth, a member of the spiritual and eternal world, no event in time such as the dissolution of the body can affect his personality. I believe this to be the lesson of evolution.

To be a whole-hearted evolutionist is, in a word, not inconsistent with either the habits or the hopes of religion, with prayer and worship, with effort so to study the Bible as to think of God and man more and more as Christ thought, and to act accordingly; nor is it inconsistent with widely diverse intellectual and spiritual temperaments.

Summary of Leading Thoughts in this Chapter

I will conclude with a brief summary of the leading thoughts on this subject at which, in my old age, I have arrived.

The discovery that the method of Creation has been that of evolution should be regarded as a Revelation to Man of the Being and Working of God.

The facts of evolution have revealed a vastness in the scales of Space and Time, and a continuity, which could not, in an earlier age, have been realized. Evolution has, therefore, corrected many crudities and errors in man's "first thoughts" of God, arising from his imperfect science—"first thoughts" which tradition and reverence for the past have long handed down, and mistakenly regarded as final revelations from God.

The idea of evolution has transformed the mutual relation of science and religion from that of rival authorities, each claiming to declare the origin, nature, duty, and destiny of man, to that of co-operators, indispensable to one another, in

the long and reverent search for the knowledge of truth, reality, and God; and in that co-operation, while one stresses the study of method and the other that of mind, the practical aim and resulting duty are being more and more clearly seen by both, as consciously to assist the growth of the higher faculties of mankind, and thus to promote the advance towards what we can learn of the high purpose of our Creator.

Nothing short of full co-operation between religion and science offers hope for the improvement of human nature through racial evolution, and the reversal of the dysgenic influences of civilization—religion, the sense of being God's agents, to show us wherein " improvement " consists, and to fortify our will to attain it; and science, a wholly truthful study of facts, to guide us wisely and rightly in the choice of methods for attaining that improvement.

It must not, however, be overlooked that the fact of evolution also conveys a grave warning. Theology and Religion are in process of evolution. The emergence of Christianity heralded great advances in the highest religious ideals of man, the advance from mythology to conscience — the sense of the Indwelling Spirit of God—and the advance from magic to morality, as the true worship and service of God. But such ideals are not secure. *Evolution is not always progress*; it is not automatic. For in evolution there is always the danger of reversion. Human nature is tenacious of its primitive tendencies, and where moral effort is relaxed and indifference prevails, and gains are not strenuously retained and increased, human nature is swept back for a time to the crudities and pathetic gropings of a past that is outgrown.

The idea of evolution is a strong incentive to right conduct, and to conduct the evolutionist assigns the highest place in religion. Evolution appeals to the sense of the Divine in man. It thus justifies and strengthens the instinct for generous, devoted, altruistic action. It heightens the sense of the value of the individual; it indicates the goal of religion; and it tends to explain to each the contending forces in industry, economics, and politics.

It suggests also a new approach to one of the oldest and profoundest subjects of speculation. For evolutionists are, in fact, restating the old insoluble speculative problem of the origin of evil in a new form, as that of the emergence of good out of, or in association with, the seemingly incongruous non-moral elements of nature.

The method of approaching the problem is, therefore, being completely reversed. It is becoming a scientific inductive study of facts in the past, and of inferences from those facts. The emergence of good *has taken place*. That is certain. Man has come to be what he is from a remote origin in which, in his consciousness, good and bad, right and wrong, had no place. So the questions come to be—How far from the study of this emergence can the existence and nature of an unseen influence, guidance, mind, purpose in the past be securely inferred? How far do the historic and present spiritual experiences of man confirm such inferences? and—most practical question of all—How best can man, having got so far, consciously co-operate with that guiding influence, and thus out of the good assist in developing a better? These are great practical, hopeful problems.

Finally we are, I think, led by the idea of evolution to see, as a distinguished living biologist has said, that " the goal of evolution is Deity ". And this goes far to confirm our Christian Faith that we see the light of the knowledge of the glory of God in the face of Jesus Christ, and our Christian ideal of life for men as that of being the conscious agents of God in the service of mankind.

Note to Section IV

I feel compelled to offer some apology for this short and very inadequate section.

The effect of the idea of evolution, both on the science of ethics and on actual standards of morality, can only be fully appreciated when seen as the last in the long series of attempts to place that science on a sound philosophical basis. To present it aright one should show in succession the non-Christian attempts from pre-Socratic days through Aristotle to Epictetus; the mediæval Christian

moralists from Ambrose to Thomas Aquinas; and the modern philosophic moralists from Hobbes to the present day.

The broad result of such a survey may be seen in works on moral philosophy. It is, I think, to show that, " apart from the co-operation of intelligent purpose ", it has been impossible to establish the science of ethics on any purely philosophical basis. And the reason is that the science of ethics, alone among the sciences, is inseparable from the antitheses of " good " and " bad ", and of " right " and " wrong ". It deals not only with what is, but also with what ought to be; and this points to a standard outside ourselves.

Evolution, by its suggestion of continuity between the human and the divine, indicates the source from which these antitheses arise, and thus tends to make scientific and philosophical the basis of morality which Christianity proclaims. But all this it has been impossible to deal with here.

L'ENVOI

Build thee more stately mansions, O my soul,
    As the swift seasons roll!
    Leave thy low-vaulted past!
Let each new temple, nobler than the last,
Shut thee from heaven with a dome more vast,
    Till thou at length art free,
Leaving thine outgrown shell by life's unresting sea.

—Oliver Wendell Holmes.

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I was requested to include some books which, like my own essay, were intended for the general reader, and others for specializing students. I have been unable sharply to divide them; but I place the introductory works early on the list.

Of works on Dogmatic Theology I have not ventured to make any list: and of those on the scientific aspect of the subject I felt that my own knowledge was quite inadequate. I therefore sought and very gratefully acknowledge supplementary assistance from my friends Dr. Guppy, the librarian of the John Rylands Library, and Dr. Barnes, the Bishop of Birmingham. Prof. J. Arthur Thomson has also greatly assisted me by making a small selection from the longer Bibliography of one of his own books on my list.

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INDEX